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Climates of Texas

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Texas is large enough to include several greatly contrasted natural landscapes, differentiated mainly on the basis of climate. Though there is a 9,020-foot difference in elevation between its highest and lowest points, vast parts of the state have relatively little local relief. For these reasons it is an excellent proving ground for testing the merits of a system of climatic mapping.

If a proposed climatic boundary across most parts of Texas has little or no significance, that fact is readily apparent to anyone familiar with its natural landscapes. This is not always the case in regions of more complicated relief. If, for example, it is contended that some particular isotherm is an important boundary in mountainous parts of California, the idea might be supported by maps showing the distribution of various plants, animals, culture traits, and many different landscape forms on a scale appropriate to the page size of the *Annals,* and still be wholly fallacious for the reason that isotherms are so closely bunched that temperatures many degrees apart occupy about the same position on the map. This possibility exists only in limited parts of trans-Pecos Texas. Elsewhere practically any landscape form or climatic subdivision worthy of attention occupies a comparatively broad area.

The purposes of the present analysis of Texas climates are threefold, (1) to test the merits of the Köppen classification as modified by the writer, (2) to present a climatic map based entirely on frequencies of climatic years, and (3) to portray the climatic landscapes of Texas.

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MODIFICATIONS OF THE KÖPPEN CLASSIFICATION

The intent of Köppen's major work was to classify the climates of the entire earth, so that a world map might show their distribution.[2] For that particular purpose the climates of approximately 1050 places were classified and the result placed on a map having an equatorial length of about 16 inches. Later, Köppen and Geiger issued a large wall map showing climatic distribution somewhat more clearly, but highly generalized from the standpoint of areas the size of Texas.

In applying the classification to a surface as small as California, with all its topographic diversity, it was necessary to modify the system in the direction of recognizing somewhat finer climatic subdivisions than Köppen had provided.[3] In testing the validity of Köppen's steppe and desert boundaries in the United States it was found desirable to give somewhat greater weight to seasonal distribution of precipitation than Köppen had considered necessary for world mapping.[4] Subsequent studies demonstrated the value of using frequencies of climatic years, rather than mean temperature and precipitation values in applying the Köppen classification.[5] These modifications made it possible to use the classification for mapping rather small regions, something neither contemplated nor approved by Köppen himself.[6]

CLIMATIC BOUNDARIES

In no two years does a place experience exactly the same weather conditions. The mean annual precipitation, for example, is established as a result of many years of observation and is not likely to occur during any single year. It cannot be emphasized too strongly that the mean annual precipitation is exceeded in less than half of all years, so that it is commonly a dangerous fiction. A temperature value, on the other hand, may be exceeded in more than half of all years.

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[2] W. Köppen: *Die Klimate der Erde,* 369 pp., Berlin and Leipzig (W. De Gruyter), 1923; in part presented in graphic form by J. B. Leighly: *Graphic Studies in Climatology: I. Graphic Representation of a Classification of Climates,* Univ. Calif. Publ. Geog., Vol. 2, pp. 55–71, 1926.

[3] R. J. Russell: *Climates of California,* Univ. Calif. Publ. Geog., Vol. 2, pp. 73–84, 1926.

[4] ————: *Dry Climates of the United States: I. Climatic Map,* Univ. Calif. Publ. Geog., Vol. 5, pp. 1–41, 1931.

[5] ————: *Dry Climates of the United States: II. Frequency of Dry and Desert Years, 1901–1920,* Univ. Calif. Publ. Geog., Vol. 5, pp. 245–274, 1932, and, *Climatic Years,* Geogr. Review, Vol. 24, pp. 92–103, 1934.

[6] *Personal communication.* Köppen's reaction to "Climates of California" was a detailed letter, explaining that his classification was intended only for the major climates of the world, not for the mapping of localized areas.

The climatic-year concept recognizes that every isohyetal line, isotherm, or other climatic isarythm differs in position from one year to the next. It advocates the idea that any particular climate, such as some type of desert, expands in areal distribution some years and contracts in others. From this it follows that climatic mapping should be based on the frequency of occurrence of such conditions as desert years, steppe years, or tundra years, rather than on the mean values of meteorological observations.

An important advantage of climatic-year analysis is the fact that it focuses attention on nuclear conditions and removes the emphasis from boundaries. The nuclear desert, for example, may be considered as the area where desert years are experienced in unbroken succession. The nuclear humid climate beyond some desert margin may be considered as the area where an unbroken succession of humid years has been experienced. Various possibilities exist for differentiating belts in the transitional zone between desert and humid areas.

While the task of drawing boundaries is one of the geographer's recognized duties, it is always important that the transitional relationships between many natural phenomena be emphasized. There is considerable merit in the idea that the best way to see various landscape changes between the Rockies and the Appalachians on a trip by train is to spend most of the time reading a book, dozing, or doing things other than observing the passing scene, except at intervals of every three hours or so. More faithful attention to the landscape may obscure important contrasts, because one scene blends so gradually into the next. A somewhat similar line of reasoning leads to the conclusion that the climatologist does well to present his conclusions on maps not too adequately supplied with reference points or detailed grid. By this device the reader is more or less forced to relegate boundary positions to their appropriate significance.

A climatic boundary should lie as centrally as possible within a zone of transition. Boundaries will take the form of lines on most maps in spite of the fact that various other cartographic techniques are available, such as blending colors or overlapping conventional patterns. If zones of transition are indicated on a map, their boundaries are likely to be lines. If various belts are indicated across some transitional zone, they take the form of fields, each with its own nuclear area and transitional margins. The many landscape changes between nuclear desert and nuclear humid climate practically defy cartographic representation. Though the person designing a map may indicate a reasonable number of transitional steps, a reader must interpolate between the nuclear parts of each step if he is to understand the transition as a whole.

Climatic boundaries in Texas are rarely sharply defined on the ground.

Between the nuclear humid mesothermal climate of eastern Texas and the nuclear steppe of the Staked Plains it is possible to recognize many transitional steps. Toward El Paso is a transition into still more arid climate, of an intensity that may be considered less than nuclear desert. Though almost all of the state has temperatures that fall within the mesothermal belt, there is a very considerable difference between Brownsville and Amarillo. To present a map designating the nuclear areas and transitional belts in such a way that they are understandable to the reader it is desirable that neither too many, nor too few, steps be shown. In the present attempt Texas has been divided into twelve parts, a number which may be sufficient to portray its climates without being overcomplicated and burdensome to understand.

TEMPERATURE BELTS

According to the Köppen classification of climates, as modified by the writer, Texas lies almost wholly in the belt of mesothermal temperatures.[7] Coldest-month temperatures average between 32 and 64.4° F. everywhere except in the northwestern corner of the state. A belt across somewhat more than the southern half of the state is characterized by an unbroken succession of mesothermal-temperature years. In the extreme south a few January temperatures have averaged above 64.4° F. In the Panhandle and along a narrow strip just south of Red River the coldest-month average now and then falls below 32° F.

If we follow the ordinary practice of using mean annual temperatures in climatic mapping and adopt the value of 32° F. for the coldest month as the boundary between microthermal and mesothermal belts, Texas would be divided into but two regions, a narrow area of microthermal temperatures, in the extreme northwest, and a broad area of mesothermal temperatures, covering the rest of the state. Further subdivision into temperature belts could be based upon cold-month isotherms intermediate between 32 and 64.4° F. This possibility seems to have less merit than taking the frequency of occurrence of what appears to be some critical value, such as 32, or 64.4° F. for the coldest month.

The method used in preparation of the accompanying climatic map (Fig. 2) was that of classifying every long-record station in the state according to frequency of microthermal, mesothermal, and tropical years during the period 1914–1931. For cartographic representation four temperature belts are indicated: (1) DC, more than half of the years microthermal, the others mesothermal, (2) CD, more than half of the years mesothermal, and the others microthermal, (3) C, all years mesothermal,

[7] R. J. Russell, *op. cit., 1926, 1931.*

and (4) CA, more than half of the years mesothermal, the others tropical. One belt of nuclear mesothermal temperature and three belts of transition are thereby indicated for the state.

The transition toward tropical temperatures occurs only in the extreme south. Harlingen experienced, between 1914 and 1931, tropical years in 1916, 1921, 1923, and 1927, a total of four in 18 years. Falfurrias and Brownsville duplicate the record except for 1927, the latter missing by a margin of one degree. The temperature belt indicated by these records is CA.

At the opposite end of the state, Dalhart experienced microthermal years in 1915, 1917, 1918, 1919, 1922, 1924, 1925, 1929, and 1930, a total of nine in 18 years. This places it squarely on the boundary between mesothermal- and microthermal-temperature belts. A small triangle northwest of Dalhart is slightly colder, or in the region DC temperatures.

The division of Texas into four belts on the basis of coldest-month temperature follows a practice applicable to all temperate-zone climates. Winter is the season of significant contrasts. Almost any lowland place between the Gulf of Mexico and the Canadian boundary may experience maximum temperatures in excess of 100° F. on one or more summer days. Summer isotherms are spaced widely. Temperatures are everywhere high enough to promote rapid growth of vegetation. It is in winter, when days grow short in higher latitudes and the inclination of the rays of the noonday sun is low, that temperature contrasts are meaningful between such points as New Orleans, Memphis, Chicago, and Duluth. In Texas there is comparatively little contrast between summer temperatures at Paris and Brownsville (82.8 vs. 84.0° F., in August), but in winter the difference is considerable (43.8 vs. 59.5° F.). A difference of 1.2° F. may be insignificant, but not one of 15.7° F.

CA belt. The transition into tropical temperatures occurs only in the lower Rio Grande Valley and along the coast, toward Corpus Christi. In this land of mild winters, tropical years are decidedly in the minority. Texas neither extends as far south nor at any place attains the tropical-year frequency of southern Florida stations.

The mildness of January in southernmost Texas is illustrated by the fact that between 1914 and 1931 the coldest average temperature for any month at Harlingen was 50° F. (Jan., 1920) and at Brownsville 53° F. (Jan., 1930). Only 13 times in 18 years did Brownsville daily minimum temperatures dip below 28° F. Six of these cold spells were in December, six in January, and one in February. Three of these low-temperature records were set during 1924, three in 1930, two in each 1917, 1918, and 1925, and one in 1919. The 13 occurrences were thus limited to six

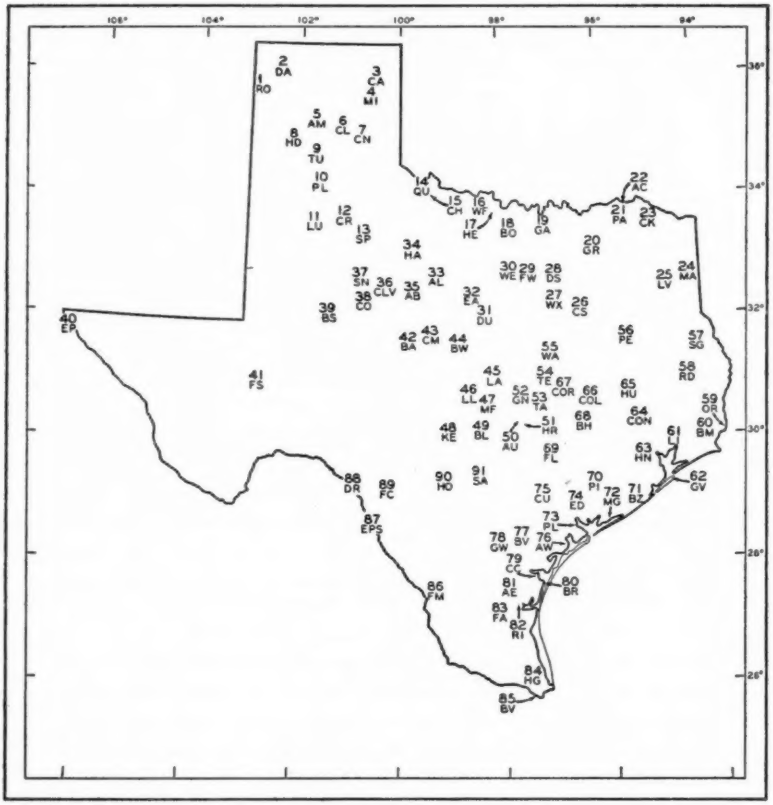


FIG. 1.—Localities mentioned in the text.

Abilene—35
Albany—33
Alice—81
Amarillo—5
Arthur City—22
Austin—50
Austwell—76
Ballinger—42
Beaumont—60
Beeville—77
Big Spring—39
Blanco—49
Bowie—18
Brazoria—71
Brenham—68
Brighton—80
Brownsville—85
Brownwood—44
Cameron—67
Canadian—3
Chillicothe—15
Clarendon—7
Clarksville—23
Claude—6
Claytonville—36
Coleman—43
College Station—66
Colorado—38
Conroe—64
Corpus Christi—79
Corsicana—26
Crosbyton—12
Cuero—75
Dalhart—2
Dallas—28
Del Rio—88
Dublin—31
Eagle Pass—87
Eastland—32
Edna—74
El Paso—40
Falfurrias—83
Flatonia—69
Fort Clark—89
Fort McIntosh—86

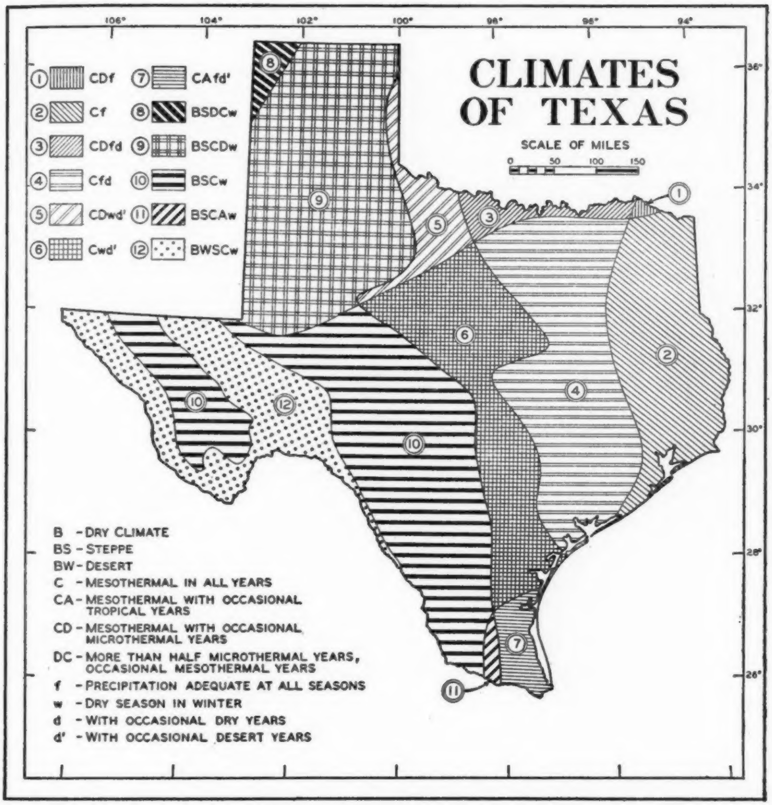


FIG. 2.—Climatic map.

Fort Stockton—41
Forth Worth—29
Gainesville—19
Galveston—62
Georgetown—52
George West—78
Greenville—20
Harlingen—84
Haskell—34
Henrietta—17
Hereford—8
Hills Ranch—51
Hondo—90
Houston—63
Huntsville—65
Kerrville—48
Lampasas—45
Liberty—61
Llano—46
Longview—25
Lubbock—11
Marble Falls—47
Marshall—24
Matagorda—72
Miami—4
Orange—59
Palestine—56
Paris—21
Pierce—70
Plainview—10
Port Lavaca—73
Quanah—14
Ricardo—82
Rockland—58
Romero—1
San Antonio—91
San Augustine—57
Snyder—37
Spur—13
Taylor—53
Temple—54
Tulia—9
Waco—55
Waxahachie—27
Weatherford—30
Wichita Falls—16

individual years. During twice as many years no dip as low as 28° F. was recorded. Farther north, Falfurrias temperatures reach 28° F. or lower, an average of four days per year. They failed to do so in 1931 and dropped that low on only one occasion during 1921, 1926, and 1927. In 1918 there were 12 occurrences of 28° F. temperature and six in each 1919, 1920, 1929, and 1930. The warmest tropical-year temperature had an average of 67° F. for January at both Harlingen and Brownsville.

CD belt. Sharply differentiated from the region of CA temperatures in southern Texas is the belt transitional to microthermal conditions in the northern part of the state. This belt includes a narrow strip along Red River and almost all of the state north of a line that swings southwestward toward the southeastern corner of New Mexico. Here a January with temperatures averaging below freezing is always in prospect and is experienced with increasing frequency northward; at Dalhart the chances are even.

Temperatures alternate between effective freeze (28° F.) and thaw (32° F.) on an average of 110 times per year at Dalhart.[8] In 1926 there were 129 alternations and in 1927, 128. The lowest frequency between 1914 and 1931 was 89, in 1918. South of the microthermal boundary these values drop sharply. The following frequency-count averages are typical in showing this transition toward warmer territory: Lubbock, 69; Quanah, 38; Fort Stockton, 33; Llano, 29; Paris, 26; Corsicana, 16; Taylor, 11; Eagle Pass, 10; Flatonia, 7; and Beeville, 6. While temperatures below 28° F. occur on an average of three times during November and nearly four in April at Dalhart, farther south they are progressively restricted to the months of December and January.

Microthermal years were experienced at Canadian in 1916, 1918, 1919, 1922, and 1930. With the exception of 1916 these years were also microthermal at Miami. Amarillo had microthermal years in 1918, 1919, and 1930. Clarendon omits 1919. Haskell, Lubbock, Plainview, Quanah, Snyder, and Spur were microthermal only in 1930. Paris, by a margin of one degree, experienced a microthermal year in 1918.

C belt. Between the CA (sub-tropical) and CD (sub-microthermal) temperature belts of southern and northern Texas lies the nuclear mesothermal region. Along its southern border places that barely excaped tropical years include Alice, Beeville, Fort McIntosh, Pierce, and Ricardo. Toward the north Albany, Abilene, Dallas, El Paso, Fort Stockton, Gainesville, and Greenville may be mentioned as having barely escaped micro-

[8] R. J. Russell: *Freeze- and Thaw Frequencies in the United States,* Am. Geophys. Un., Trans. 1943, pp. 125–133.

thermal years. Most of the larger cities of Texas lie within the nuclear mesothermal temperature belt.

PRECIPITATION BELTS

In so far as climatic boundaries in Texas depend on temperature the trends are about east-west. Precipitation belts have more of a north-south alignment. From a very humid eastern region there is gradual change westward into marginal desert.

The determination of precipitation effectivity is complicated because it should consider such factors as amount of precipitation, the season at which it comes, temperature, wind conditions, evaporation rates, and atmospheric vapor pressure. Various methods have been devised to combine and evaluate some of these factors in order to obtain a reasonable index of climatic wetness or dryness. Some methods appear admirable from a theoretical standpoint but prove unuseful to regional climatologists because they involve factors not commonly measured, or abundantly tabulated. The weather records available in sufficient quantity for climatic mapping are mainly tabulations of precipitation and of maximum and minimum temperatures, each recorded on a daily basis. Both Köppen and Thornthwaite climatic classifications limit themselves to these factors.[9]

The fundamental postulates of either system of classification are, (1) more precipitation is necessary under warmer than under cold mean annual temperature conditions to produce a given departure from desert aridity, and (2) more precipitation is necessary if a large proportion falls during the warm season of the year. The higher evaporation rates associated with higher temperature reduce precipitation effectivity.

In the Köppen classification, as modified by the writer, a place is recognized as humid with a mean annual temperature (73.2° F.) and seasonal precipitation distribution characteristic of Brownsville only if the annual precipitation is in excess of 23.5 inches. With the mean annual temperature (56.5° F.) and seasonal distribution of Amarillo it need receive but 22 inches. Desert and steppe, the fundamental degrees of aridity, are separated on the basis of 16.5 inches for Brownsville conditions and slightly less than 13 inches for Amarillo conditions. At both extremes, in Texas, the values are somewhat higher than the 10-inches-or-less-for-desert and 20-inches-or-less-for-steppe commonly advocated by laymen. The reason for this is that warm-season precipitation is widespread in Texas. A place with Brownsville temperatures would need less than 18 inches to be humid were the precipitation concentrated in the winter season. With Amarillo temperatures it would need but 14 inches.

[9] C. W. Thornthwaite: *The Climates of North America*, Geogr. Rev., Vol. 21, pp. 633–655, 1931, *The Climates of the Earth*, *idem.*, Vol. 23, pp. 433–440, 1933.

In the following discussion any year receiving less precipitation than is required to maintain humid climate is called a dry year. The term thus has a specific, quantitative meaning and is not used in its popular sense. Any year having less precipitation than is required to maintain steppe climate is called a desert year. All desert years are also dry years. Steppe years are intermediate between humid years and desert years.

Texas could be divided into a great many precipitation belts on the basis of humid, steppe, and desert year frequencies. Six have been designated on the climatic map (Fig. 2), (1) f, all years humid, adequate precipitation at all seasons, (2) fd, similar to f, with some dry years, but less than 50 per cent dry-year frequency, no desert years, (3) fd′, similar to fd, but with occasional desert years, (4) wd′, more than 50 per cent of years humid, distinct dry season in winter, with occasional desert years, (5) BSw, more than 50 per cent steppe years, with occasional humid or desert years, distinct dry season in winter, and (6) BWsw, more than 50 per cent desert years, with occasional non-desert years, distinct dry season in winter.

The records of 20 years, 1901–1920, have been used to map precipitation belts.

f belt. The most humid part of Texas is a strip less than 150 miles wide that roughly parallels the eastern boundary of the state. Beaumont, Brazoria, Clarksville, Longview, and Palestine had an unbroken succession of humid-year records for the period investigated. Houston and Huntsville had a dry year in 1917, each by a small margin. Paris had a dry year in 1910. To the west all parts of the state have experienced drought sufficiently varied in degree and frequency for use in the determination of precipitation belts. Only the f belt lies within the nuclear region of humid climates.

fd belt. Adjacent to humid east Texas and also extending from Red River to the Gulf is the territory that experienced at least one dry year, but no desert year. Within it is Austin, with six dry years between 1901 and 1920. Other frequencies of dry years include, Bowie, 3; Brenham, 4; College Station, 2; Forth Worth, 3; Gainesville, 3; Henrietta, 3; Lampasas, 4; Temple, 2; Waxahachie, 2; and Weatherford, 3.

fd′ and wd′ belts. Next west lies a belt extending from western Oklahoma to the Rio Grande Valley, where most years were humid, but drought of desert-year intensity occurred occasionally. Abilene experienced 9 dry years out of 20, one of which was a desert year. In the following representative list, the number of dry years, 1901–1920, precedes the hyphen and the number of desert years follows it. The first number is always larger, because desert years are also included in dry-year counts. The

difference between the two values is the number of steppe years. Within the d′ belt are, Albany, 7–1; Beeville, 3–2; Blanco, 5–1; Brighton, 7–1; Brownsville, 10–1; Brownwood, 8–1; Claytonville, 7–3; Coleman, 4–2; Colorado, 10–3; Corpus Christi, 9–2; Dublin, 5–1; Georgetown, 5–1; Hondo, 6–1; and Waco, 1–1. The year 1917 was a desert year at practically all of these places. Claytonville, Coleman, and Colorado experienced desert years in 1910 and, excepting Coleman, again in 1912. The year 1900 was a desert year at Blanco and Dublin.

Within the d′ belt a distinction is made between territory with comparatively non-seasonal (f) precipitation and that with rather pronounced winter dryness (w). The former lies to the south, along the coast. The latter is far more widespread, occurring not only along the whole western margin of the humid belt but in all of the dry-climate territory as well.

Humid belt summary. The four precipitation belts just described belong to the humid-climate territory that extends eastward to the Atlantic and northward into Canada. The western boundary lies rather close to the 100th meridian, the traditional dividing line between humid and arid climates in the United States.

Conditions transitional toward the humid-arid boundary have been emphasized by the introduction of two precipitation belts defined on the basis of drought intensity. The eastern transitional belt is characterized by years of moderate drought and the western by years of extreme drought. Farther west all climates are arid, with the possible exception of those near the summits of peaks along the New Mexico boundary, the Chisos Mountains, and a few other places not served by the Weather Bureau. Dry-year frequency is in excess of 50 per cent in this arid part of Texas.

BSw belt. Nuclear steppe may be considered as territory subject to dry-year frequencies in excess of 50 per cent and desert-year frequencies of less than 50 per cent. In Texas it extends southward from the High Plains, across the Edwards Plateau, to the Rio Grande as a belt everywhere over 100 miles in width and at some places about twice that wide. Nuclear steppe also is extensively developed in trans-Pecos Texas. Dry winters are characteristic everywhere.

Using the convention of placing dry years ahead of the hyphen and desert years behind, typical records from the nuclear steppe include, Amarillo, 13–1; Ballinger, 11–5; Big Spring, 14–6; Claude, 12–2; Crosbyton, 14–2; Eagle Pass, 17–8; Fort Clark, 16–5; Haskell, 11–3; Llano, 12–6; and Plainview, 14–4.

BWSw belt. The territory subject to desert-year frequencies in excess of 50 per cent is properly considered desert, but not of nuclear variety. In widespread parts of southern California and southern Arizona, and over

limited parts of several other states, the desert-year frequency is 100 per cent. Possibly this condition is attained in valleys of the Big Bend region of Texas, but Weather Bureau records fail to demonstrate an actual case. Transitional desert, or salt steppe, is indicated by the following records, El Paso, 20–17; Fort McIntosh, 16–11; and Fort Stockton, 18–10.

CLIMATIC REGIONS

A combination of temperature and precipitation belts, as defined above, yields a climatic map of Texas (Fig. 2). Twelve different regions are shown, only two of which are nuclear climates. The Cf region has purely mesothermal temperatures and humid years. The BSCw region has purely mesothermal temperatures and nuclear steppe climate. Between these nuclear mesothermal precipitation belts are two transitional zones, differentiated on the basis of drought intensity. To the north are transitional temperature belts, differentiated on the basis of microthermal-year frequency, and to the south belts determined by tropical-year frequency. To the west is desert, not dry enough to be considered nuclear. For a discussion of climatic regions it is not necessary to examine the characteristics of all twelve areas mapped, nor desirable that we consider only nuclear climates. Discussion may be limited to four significant climatic regions. Each of these areas raises at least one question deserving some comment.

Humid east Texas. The climates designated Cf and CDf lie toward the Sabine, in easternmost Texas. They are alike in sharing high probability of escaping extreme drought during years when the dry climates are most expanded in area. They differ mainly in the fact that the more northern has experienced some years with average coldest-month temperatures below freezing.

Between the winter mildness of the Gulf Coast and comparative severity along Red River the transition is gradual and, from the standpoint of the entire eastern United States, not particularly striking. Texas barely reaches the margin of CDf climate.

Clarksville, in the CDf region, receives an annual precipitation of 48.22 inches, nearly three inches falling in even its driest months, yet has an annual snowfall average of only 2.3 inches. The depth of precipitation added by snow is somewhat less than one-tenth of 2.3 inches. Severity of winter is much greater toward the west, as shown by the fact that annual snowfall is almost inversely proportion to annual precipitation. In the following tabulation the annual precipitation precedes and the annual snowfall follows the hyphen, each being expressed in inches, Dallas, 37.00–3.2; Henrietta, 26.75–3.5; Wichita Falls, 28.41–5.5; Chillicothe, 25.60–7.5;

Quanah, 24.41–7.8; Amarillo, 21.59–20.8; Hereford, 19.80–21.2; and Romero, 21.44–23.7.

Severe storms are more numerous in humid east Texas than in other parts of the state for the reason that vast amounts of energy lie latent in atmospheric moisture. Cold fronts set off numerous tornadoes, especially during late spring. Hurricanes, from the Gulf, not uncommonly find air humid and warm enough to permit travel overland for tens, and even hundreds of miles, especially in early fall. Thunder is commonly heard on more than 50 days per year.

Transitional east-central Texas. The climates designated Cfd and CDfd form the first step and those designated CDwd′, Cwd′, and CAfd′ the second in the transition between humid east Texas and the nuclear steppe to the west. Occasional droughts, with increasing severity westward, have been experienced throughout the transitional territory. Although the entire region is ordinarily mesothermal in temperature, winter mildness in the extreme south is so pronounced that an occasional tropical year occurs, while to the north some years are microthermal. With greater distance from humid east Texas and from the Gulf Coast of southern Texas comes a more and more pronounced tendency toward winter dryness.

Storminess generally decreases westward, toward dry climates. One index useful in demonstrating this fact is precipitation intensity. As a general rule the intensity of rainfall during short intervals of time is about proportional to annual precipitation. The desert, instead of being a land of cloudbursts, is actually a region of floods resulting from rapid runoff.[10] Texas records demonstrate how this characteristic of precipitation changes from the humid east to the arid west.

Between 1914 and 1930 the following cases of daily precipitation in excess of 10 inches were recorded, Alice (10.50 inches, Sept. 15, 1919); Arthur City (10.50, 5–12–20); Austin (11.00, 9–9–21); Austwell (11.40, 7–22–19); Beaumont (12.76, 5–19–23); Cameron (12.45, 9–10–21); Conroe (13.85, 5–30–24); Cuero (11.96, 7–23–19); Edna (10.00, 6–22–21); George West (12.00, 9–15–19); Hills Ranch (16.02, 9–10–21); Marble Falls (11.00, 9–10–21); Marshall (10.60, 2–26–21); Matagorda (10.92, 10–24–14; 10.10, 6–22–21); Orange (10.05, 5–28–15); Port Lavaca (10.54, 10–24–14); Ricardo (11.30, 6–21–24); Rockland (11.06, 5–28–29); San Augustine (10.60, 8–18–15); and Taylor (16.11, 9–9–21). Thirteen different storms are represented in this tabulation, occurring during all months from April to October, with a maximum of five in May.

Actual precipitation intensity is reported only by Weather Bureau

[10] R. J. Russell: *The Desert Rainfall Factor in Denudation*, XVI Geological Congress, Washington, 1933, Comptes Rendus, pp. 753–763, 1936.

stations equipped with tilting-bucket rain gages. An intensity of at least one-half inch during any five-minute interval was reported the following number of times, between 1914 and 1930, Abilene, 3; Amarillo, 0; Corpus Christi, 1; Del Rio, 2; El Paso, 0; Fort Worth, 1; Galveston, 9; Palestine, 2; San Antonio, 5; and Taylor, 3. An intensity of two inches per hour (half that required by a commonly accepted definition of cloudburst[11]) occurred the following number of times during the same years, Abilene, 7; Amarillo, 0; Corpus Christi, 11; Del Rio, 3; El Paso, 0; Fort Worth, 3; Galveston, 15; Palestine, 3; San Antonio, 6; and Taylor, 5. The greatest intensity for any single hour was recorded at Galveston, 5.31 inches, October 22, 1913.

Most of the cases of extraordinary precipitation intensity tabulated above are from places in humid east Texas or in the wetter parts of the zone of transition toward dry climates. Few are from places actually in the dry climates. Cyclonic disturbances sufficiently intense to be classified as severe storms require greater atmospheric humidity than occurs in the dry climates, excepting under most unusual circumstances.

Steppes of west-central Texas. The climates designated BSDCw, BSCDw, BSCw, and BSCAw are dry, but not intensely arid. The frequency of mesothermal-temperature years is 100 per cent across somewhat more than the southern half of the Texas steppe. Toward the lower Rio Grande a small area experiences an occasional tropical year. Over most of the Panhandle microthermal years occur with increasing frequency northward until, in the extreme northwestern corner of the state they slightly out-number mesothermal years. There is thus greater diversity in coldest-month temperatures in the steppe than occurs anywhere to the east, in the humid and transitional belts of Texas.

Temperature ranges of all varieties, such as between day and night, winter and summer, or between one day and the next, are relatively pronounced in the drier parts of Texas. The oft-repeated statements concerning the inadequacy of barbed-wire fences between Amarillo and the North Pole refer to sudden drops in temperature, rather than to the severity of minima themselves.

The highest temperature ever recorded at Amarillo was 106° F. and the lowest, –16° F., a range of 122° F. between record temperatures. This is modest enough in comparison with Miles City, Montana, where a range of 177° F. has been established between records of 112° F. and –65° F. Both Dalhart and Paris have exceeded the Amarillo range (110 to –17 in the former case and 114 to –13 in the latter) by 5° F. Tulia has

[11] W. J. Humphreys: *Physics of the Air,* New York, 2 ed., 1929, p. 267.

experienced a low of –23° F., which appears to be a state record. At the other extreme are readings of 117° F. at Big Spring and 116° F. at Henrietta.

Extreme ranges in temperature increase both westward, in the dry climates, and northward, toward the region of greater seasonal contrasts. In the coastal belt extreme ranges are commonly well under 100° F., but along Red River, in the Panhandle, and in trans-Pecos Texas they commonly attain 110° F., and some rise above 120° F. The following tabulation brings out this point, Clarendon, 123° F. (112° F. to –11° F.); Fort Stockton, 121 (114 to –7); Corsicana, 120 (113 to –7); Eastland, 115 (110 to –5); Palestine, 114 (108 to –6); Brenham, 113 (111 to –2); Kerrville, 113 (109 to –4); El Paso, 111 (106 to –5); Eagle Pass, 108 (115 to 7); Beeville, 103 (108 to 5); Falfurrias, 102 (112 to 10); Liberty, 100 (108 to 8); Del Rio, 99 (111 to 12); Brownsville, 92 (104 to 12); and Corpus Christi, 91 (102 to 11).

Low temperatures in Texas commonly accompany north winds and clear skies, in polar-Canadian air. Along the abrupt fronts of "northers" vast quantities of dust may be swept up, to be carried across the steppe and into adjacent humid belts. Within a few hours of the passage of a front the temperature may drop several tens of degrees. Farther eastward, where decidedly humid air-masses are invaded, squalls, tornadoes, and intense precipitation commonly occur along the fronts, but in the steppe the invaded air is ordinarily too dry for such storminess. The maximum wind velocity at Amarillo, however, is supposed to have been 84 miles per hour, which is higher than the velocity of 71 miles measured at Galveston on August 17, 1915. It falls far short of the unmeasured velocities of gusts associated with hurricanes or those occurring centrally in tornadoes. The average wind velocity across the plains of the Texas Panhandle is about 25 per cent higher than that in humid east Texas.

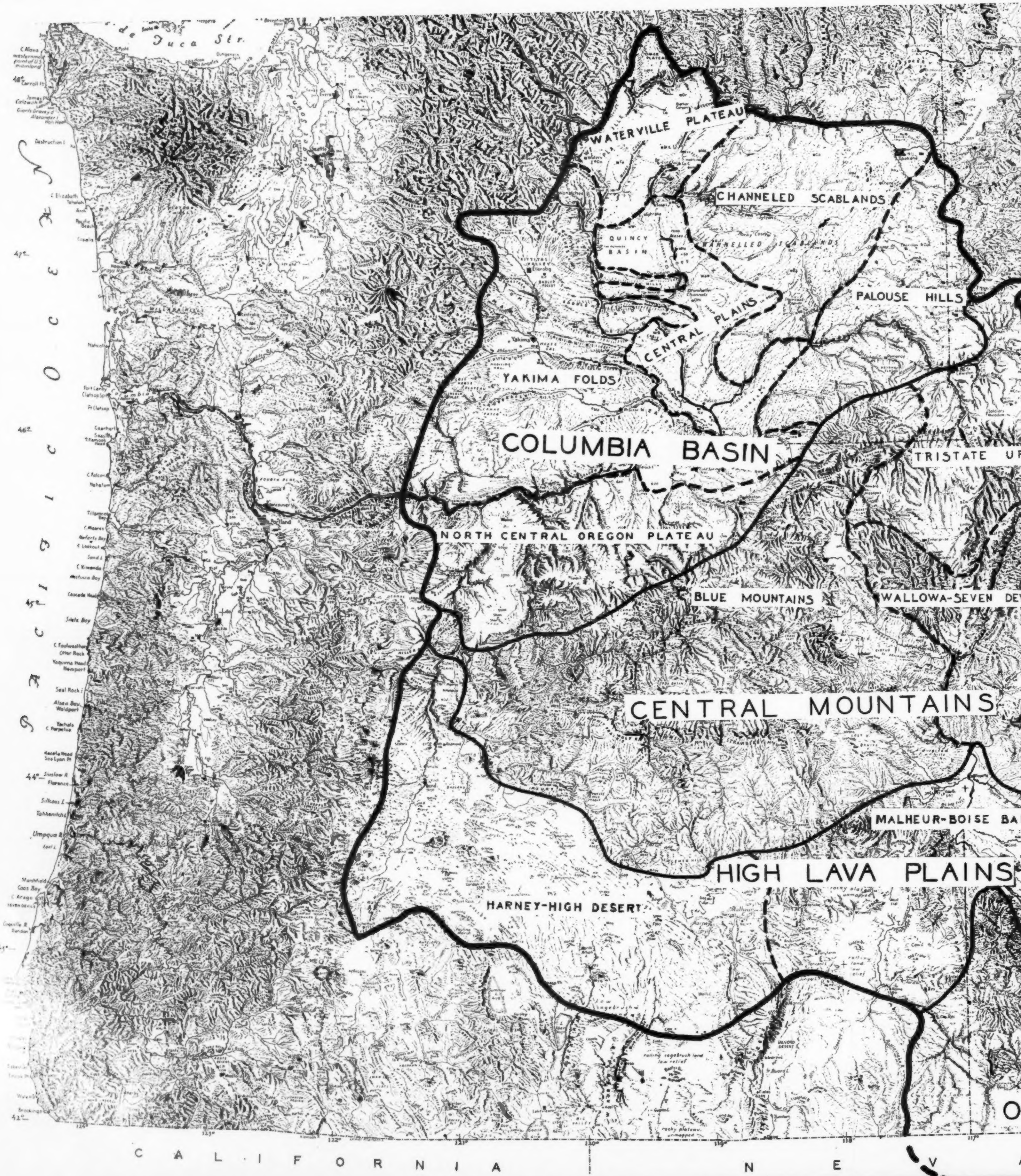
Desert trans-Pecos Texas. The BWSCw region is characterized by a majority of desert years. Temperature years are strictly mesothermal. Weather Stations are few along the Pecos Valley and westward, so climatic mapping must follow rather conventionalized patterns. In general, desert is expected along the valleys and steppe climate in the uplands. Some of the highest summits apparently reach humid climate and some of the deeper valleys may experience desert years in unbroken succession.

El Paso boasts of clear skies with ample reason; the sun shines some 80 per cent of the time it remains above the horizon.

Reduced atmospheric humidity promotes somewhat wider daily temperature ranges than occur in similar latitudes to the east. El Paso has an average temperature of 57.6° F. during the warmest part of January

days, about 5° F. lower than occurs at either San Antonio or Houston at the same time. Prior to sunrise the thermometer typically drops to 32.3° F., which is over 10° colder than the corresponding temperature at San Antonio and nearly 12° below Houston. June is the warmest month at El Paso, the average daily range being between a mean maximum of 93.6° F. and minimum of 68.0° F. August is the warmest month both at San Antonio and Houston, the respective ranges being from 94.7 to 73.2 and from 92.6 to 74.1. The early seasonal high temperature at El Paso is in consequence of the fact that nearly 40 per cent of the 8.7-inch annual precipitation falls during July and August.

The more arid parts of Texas are attractive not only for their almost rainless, sunny, and relatively mild winters but also because they offer a welcome relief from the oppressive humidity and warm nights characteristic of summers farther east. The steppes and deserts are places toward which, from the standpoint of personal comfort, Texans commonly turn envious eyes.


WATERVILLE PLATEAU
CHANNELED SCABLANDS
QUINCY BASIN
CENTRAL PLAINS
PALOUSE HILLS
YAKIMA FOLDS
COLUMBIA BASIN
TRISTATE U
NORTH CENTRAL OREGON PLATEAU
BLUE MOUNTAINS
WALLOWA-SEVEN DEV
CENTRAL MOUNTAINS
MALHEUR-BOISE BA
HIGH LAVA PLAINS
HARNEY-HIGH DESERT
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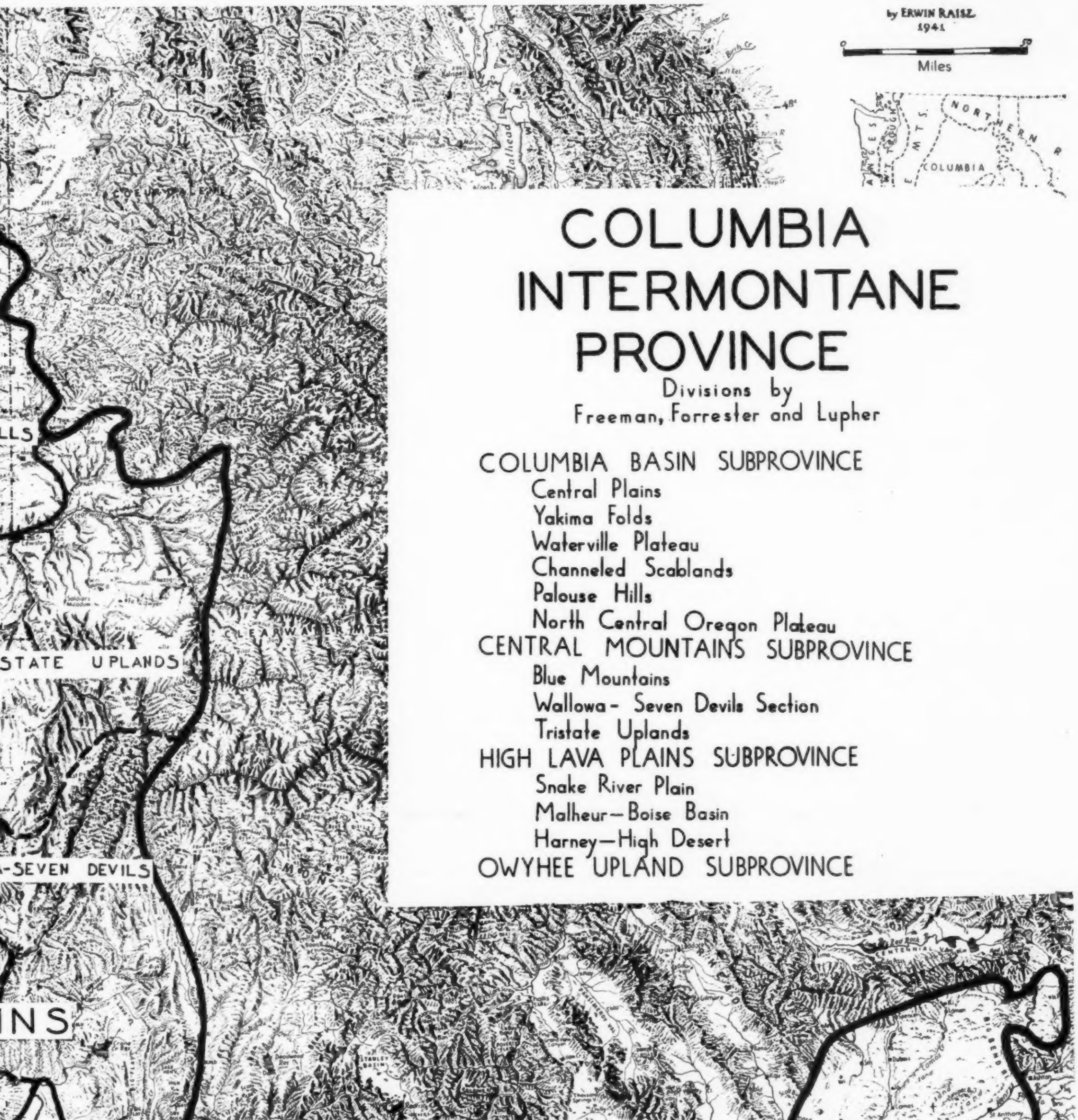
by ERWIN RAISZ
1941
Miles
COLUMBIA
INTERMONTANE
PROVINCE
Divisions by
Freeman, Forrester and Lupher
COLUMBIA BASIN SUBPROVINCE
Central Plains
Yakima Folds
Waterville Plateau
Channeled Scablands
Palouse Hills
North Central Oregon Plateau
CENTRAL MOUNTAINS SUBPROVINCE
Blue Mountains
Wallowa - Seven Devils Section
Tristate Uplands
HIGH LAVA PLAINS SUBPROVINCE
Snake River Plain
Malheur—Boise Basin
Harney—High Desert
OWYHEE UPLAND SUBPROVINCE
LLS
STATE UPLANDS
A-SEVEN DEVILS
INS
BOISE BASIN
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SNAKE RIVER PLAIN
OWYHEE UPLAND
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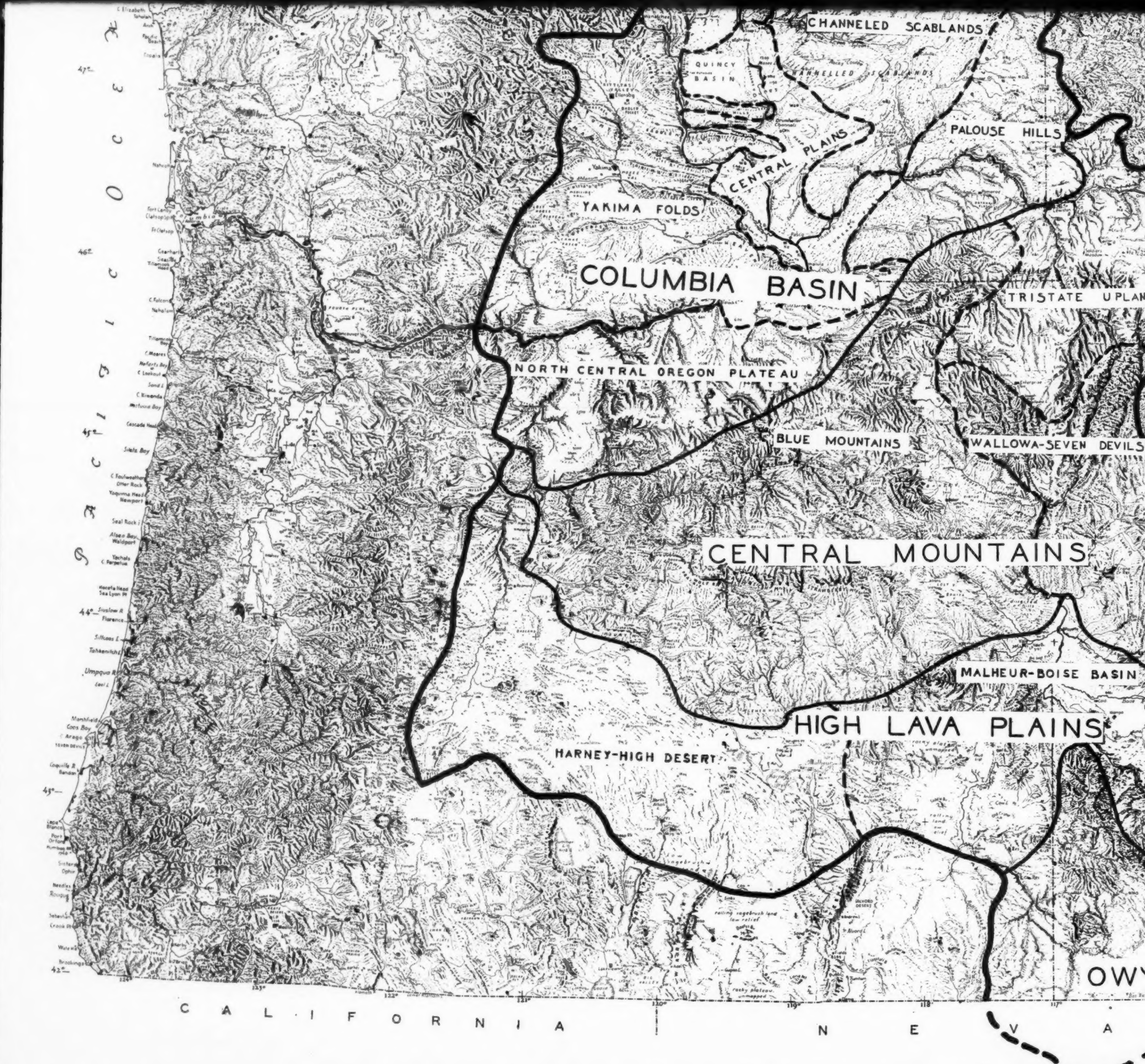
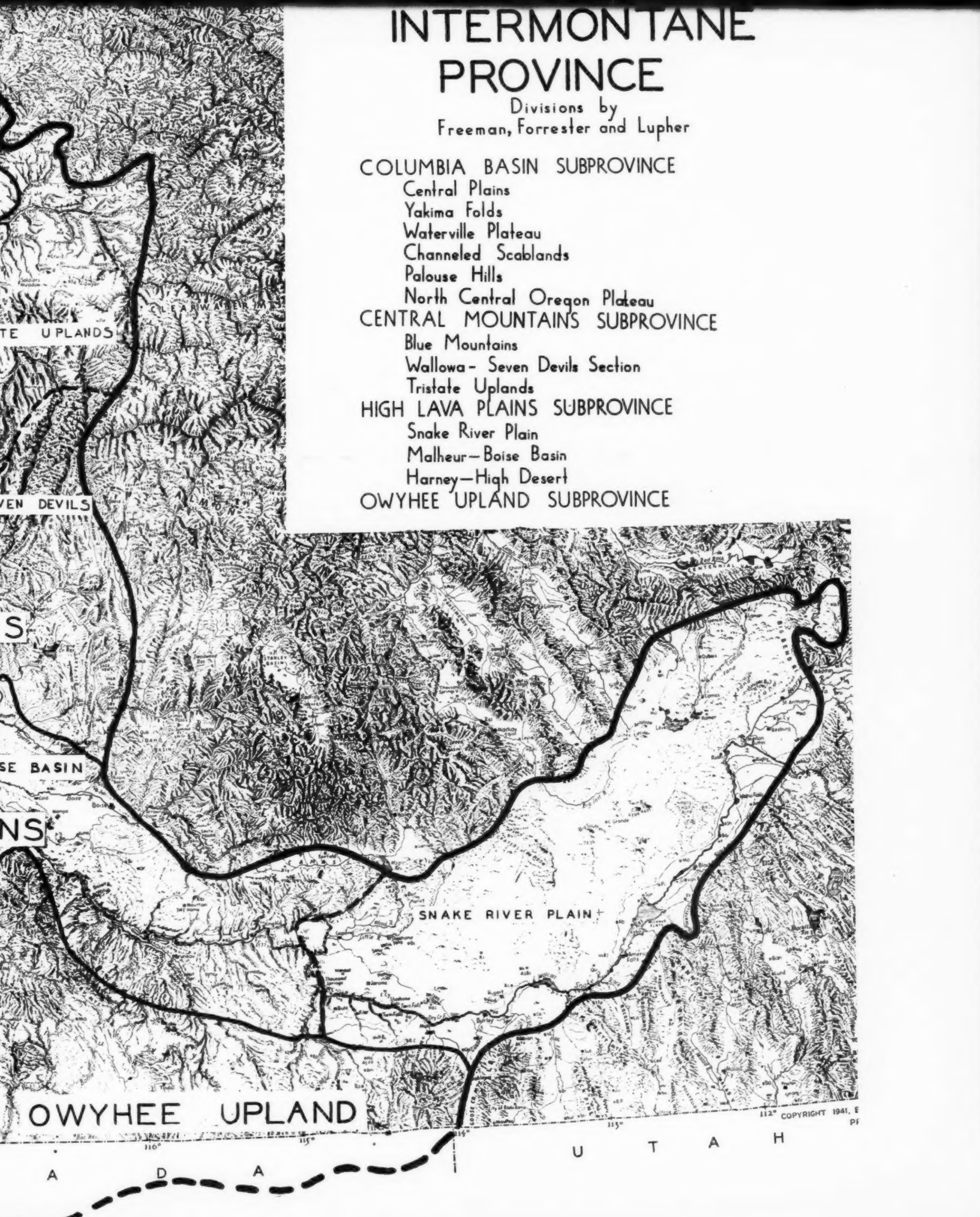


FIG. 3.—Columbia Intermontane province divided into sections. The base map used is published by Erwin Raisz and is us



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Physiographic Divisions of the Columbia Intermontane Province

OTIS W. FREEMAN, J. D. FORRESTER AND R. L. LUPHER*

INTRODUCTION

The classification and nomenclature of the physiographically different landforms of the United States has been of outstanding interest to the Association of American Geographers ever since the society was organized. The Association undertook the problem of delineating physiographic regions of the country and cooperated with the United States Geological Survey and other government agencies in such studies. In 1914 in volume 4 of the "Annals" articles were published by W. L. G. Joerg on "The Subdivision of North America into Natural Regions" and by N. M. Fenneman on "Physiographic Boundaries Within the United States." [1] In December, 1914, a round-table conference was devoted to the subject at the Chicago meeting, following which a committee headed by N. M. Fenneman as chairman prepared a report on the "Physiographic Divisions of the United States" that was published in the "Annals" in 1916,[2] and received wide acceptance. In 1928 the paper was reprinted with a few changes.[3] Still later Fenneman[4] described the western half of the country in detail in the "Physiography of the Western United States" that has been generally considered the leading authority on the names and boundaries of the physiographic regions.

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The base map used in preparing Figure 3 is the "Landforms of the Northwestern States" drawn by Erwin Raisz of the Institute of Geographical Exploration, Harvard University, and is used by his permission.

[1] W. J. G. Joerg, Annals Ass'n Amer. Geogrs., Vol. IV, pp. 55–83.

N. M. Fenneman, Annals Ass'n Amer. Geogrs., Vol. IV, pp. 84–134.

[2] N. M. Fenneman: *Physiographic Divisions of the United States,* Annals Ass'n Amer. Geogrs., Vol. VI, pp. 19–98.

[3] Same title, Annals Ass'n Amer. Geogrs., Vol. 18, pp. 261–353.

[4] N. M. Fenneman: *Physiography of the Western United States,* McGraw-Hill Book Co., New York, 1931.

However, it was recognized by Fenneman that any map showing boundaries of natural physical units must be subject to alteration and refinement as knowledge increases, and the authors of the present paper feel that a revision of names and boundaries is needed in the area that lies between the Cascade Mountains and the northern and central Rocky Mountains north of the Basin and Range province. Numerous geologists have published descriptions of the surface features and general geology of portions of eastern Washington and Oregon, southern and western Idaho, and central-northern Nevada—which are those areas to be discussed and integrated in this paper—but articles that cover the entire province are rare. Anderson[5] has discussed the divisions of the "Columbia Plateau" in Idaho, and preliminary conclusions written by Freeman[6] are modified in the present paper. There are two primary reasons for the present revision. Foremost is the conviction that this physiographically diverse region needs certain major changes in divisions and boundaries. Secondly, is the desire to counteract erroneous concepts that are gaining wide circulation in textbooks and standard reference works.

The authors of the present paper are of the opinion, therefore, that the region should be defined physiographically and that (1) a number of changes should be made in the boundaries and subdivisions, and (2) that a better name for the region is "Columbia Intermontane province" since the relief features are too diverse to be properly designated a "plateau."

A popular idea of the region as a whole is that it is built up of nearly horizontal sheets of lava, the surface of which is flat or rolling, to form an elevated plateau. Although Fenneman recognized that there were many variations from this simple character, others have failed to make this clear. It is true that the extrusions did operate to build surfaces of low relief, and where lava invaded marginal tracts of the northern Rocky Mountains, a marked change in topography now coincides with the margin of the flows. Yet lavas are not wholly distinctive of the Columbia province for they extend into adjacent provinces on the north, southeast, south, and west, and the original lava plain has been widely modified by deformation, erosion, and sedimentation. While much of the northern and southern portions of the Columbia province can be described as flat or rolling, these two parts have important physiographic differences, and high mountains intervene.

[5] Alfred L. Anderson; *Physiographic Subdivisions of the Columbia Plateau in Idaho,* Jour. Geomorphology, Vol. 4, pp. 206–222, Oct., 1941.

[6] Otis W. Freeman: *Physiographic Divisions of the Columbia Plateau,* Yearbook Ass'n Pac. Coast Geographers, Vol. 6, pp. 12–20, Cheney, Wash., 1940.

———— and Howard H. Martin: *The Pacific Northwest,* John Wiley and Sons, New York, pp. 59–76, 1942.

Although in the literature, one finds repetitions of the assertion that the lavas poured out upon a mountainous topography, actually this condition has been observed mostly near the margin of the Rocky Mountains, and in other places the lavas lie on a surface of low relief. Some writers visualize the mountains as largely or entirely island masses in a lava plateau, whereas only very small parts of the mountains have that character.[7]

The northern part of the region (Figs. 1 and 3), here termed the Columbia Basin, is primarily a large, low basin which is divided into minor basins by prominent structural ridges. South of the Columbia Basin a complex mountainous tract that includes the Blue Mountains and several other high uplifts, with altitudes of more than 9,000 feet above the floor of the Basin, is here called the Central Mountains. South of the Central Mountains are broad expanses of young lava plains that occupy much of southern Idaho and southeastern Oregon; most of the surface lies about 4,000 feet above sea level, and therefore this area is named the High Lava Plains. The lava plains are modified on the south by the fault block topography of the Basin and Range province, but between the plains and faulted ranges in southwest Idaho, southeast Oregon and northern Nevada lies a prominent upland consisting of plateaus crossed by deep canyons and including a maturely eroded mountain mass higher than the surrounding surfaces. This unit is called the Owyhee Upland. In our opinion these four units: Columbia Basin, Central Mountains, High Lava Plains, and Owyhee Upland are so distinct and physiographically different from each other that they deserve higher rank than the sections generally recognized by Fenneman elsewhere in the country, particularly the eastern United States, and we have called them subprovinces.

Our principal departures from Fenneman's classification of his "Columbia Plateau" (compare Figs. 1 and 2) are: (1) a considerable expansion of his Blue Mountain section westward to include the Aldrich, Ochoco, Maury and Mutton mountains, and the inclusion of this section with the Wallowa-Seven Devils mountains and Tristate Uplands areas to form the Central Mountains subprovince; (2) the creation of the Owyhee Upland subprovince from part of Fenneman's Payette section; (3) the assignment of subprovince rank to the Columbia Basin, which was mostly included in Fenneman's Walla Walla Plateau section; and (4) the assignment of sub-

[7] Wallace W. Atwood: *The Physiographic Provinces of North America,* Ginn and Co., New York, pp. 408–409, 1940.

Isaiah Bowman: *Forest Physiography,* John Wiley and Sons, New York, pp. 207–209, 1911.

Frederic B. Loomis: *Physiography of the United States,* Doubleday, Doran & Co., New York, p. 296, 1937.

province rank to the High Lava Plains created out of the Snake River Plain, Harney and part of the Payette sections of Fenneman, to which is also added an area of cinder cones and recent lava flows near Bend, Oregon, placed by Fenneman with the Walla Walla Plateau.

The validity of these four new subprovinces rests not only on the topographic differences between mountains, plains and basins, but also on

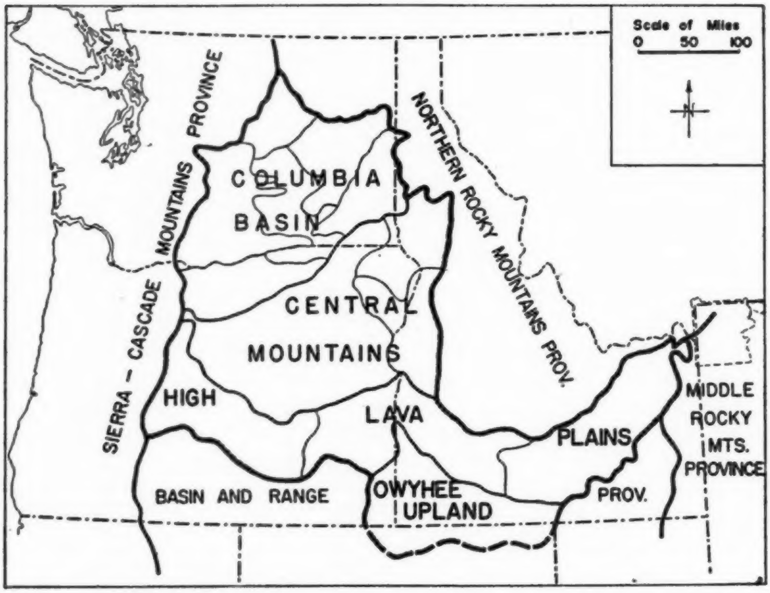

FIG. 1.—Relative location and subprovinces of the Columbia Intermontane province.

marked geomorphic differences. These differences can be best demonstrated by comparing the Columbia Basin with its counterpart, the High Lava Plains, on opposite sides of the Central Mountains. Both contain broad expanses of moderate or low relief, but the two regions would be geomorphically distinct even if the mountain ranges did not intervene. The lavas of the Columbia Basin are basalts of middle and late Tertiary age, and the original lava plain was modified in some regions by erosion and in others covered to depths of hundreds of feet by lake and stream sediments before the last episode of diastrophism and erosion, which was largely, if not entirely, confined to the Pleistocene. The last deformation defined the major basin character by depressing the lavas below sea level in the center of the region, by elevating the Cascades to the west and the

Central Mountains to the south, and by elevating the eastern and northern margins where the border of the province was already well defined by the mountainous surface that comes up from beneath the lavas at the western margin of the Rocky Mountains. Within the Columbia Basin various local basins and prominent structural ridges were formed. The dissection initiated by the deformation has considerably modified the structural surface

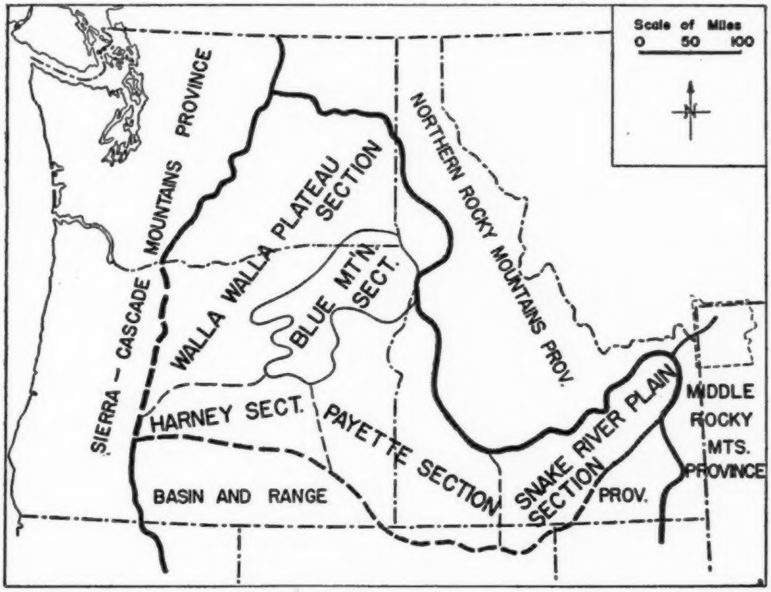

FIG. 2.—Sub-divisions of the Columbia Plateau province according to Fenneman.

and produced a number of deep canyons across structural ridges and in the upper slopes of the basin. In this last episode, which included the glacial stages, the surface was further modified by deposition of lake and stream sediments, by wide distribution of loess, and by the carving of scabland channels. As a consequence of all these post-lava events there are few, if any, remnants of the original lava plain in the present land surface.

The High Lava Plains, in contrast, present a very youthful surface of low relief which, in large part, is the original constructural surface of Pliocene, Pleistocene and Recent lavas. Major streams, such as the Snake, Owyhee and Malheur, have cut canyons to depths of several hundred feet, and a veneer of alluvium masks the lava surface in some regions, notably

the downwarped Harney Basin. But elsewhere there are broad expanses of the original lava plain. Above the plain, especially in the western part, rise hundreds of cinder cones and small volcanic mountains. In contrast, recent cinder cones are unknown in the Columbia Basin. In the High Lava Plains the topographic record of pre-Pleistocene erosion is now largely obliterated by younger formations. Freshwater sediments account for a large part of the filling in the Snake River downwarp, but in most places the sediments are capped by lava flows which now form prominent rimrocks. By the end of the Pliocene, and perhaps as late as the Pleistocene, the region was a plain of low relief. Later uplift and gentle warping initiated the present erosion cycle, which has made little headway except in westernmost Idaho and easternmost Oregon where soft sedimentary deposits and upwarping have facilitated erosion. In other regions volcanism continued into the Pleistocene or Recent, delaying or counteracting dissection and, in addition, producing many small volcanic cones.

Thus in the Columbia Basin region a constructional lava surface has been considerably modified by deformation, erosion and deposition operating since the Miocene epoch. In the High Lava Plains the constructional process continued even into Recent time and the surface is, in large part, a little-modified lava plain.

The Central Mountains subprovince includes a broad belt of mountains and dissected uplands that extend from the pre-Tertiary rocks of central Idaho westward to the Cascade Range. It includes the Blue Mountain section of Fenneman, enlarged to contain other mountainous and upland tracts that lie between the Columbia Basin and the High Lava Plains. In general character the mountain subprovince is a broad uplift with minor ranges, basins, plateaus and uplands marked by local warping and faulting, the whole being modified by erosion which, in the higher portions, has developed mature topography. The highest mountains rise 5,000 to 6,000 feet above the High Lava Plains and more than 9,000 feet above the bottom of the Columbia Basin, and the physiographic history of the Central Mountains combines some of the distinctive features of both adjacent regions. In this area, lavas, largely basalts, along with local sedimentary deposits, built up a broad plain, but several island-like areas of mountainous prelava topography, carved in pre-Tertiary rocks, remained above the plain. In the late Miocene and Pliocene, the lavas were warped, uplifted, and eroded to a stage of maturity, with maximum relief of over 2,000 feet. In the southern Blue Mountain section the low portions of the mature surface were buried by the sediments and lavas that built up the High Lava Plains. The region was further uplifted and deformed probably in the early Pleistocene; streams were rejuvenated in the regions that had been

undergoing erosion since the Miocene deformation, and the young constructional surfaces were trenched by youthful stream courses. The Central Mountains surface is of youthful or early mature aspect in most places, partly because of the newly uplifted portions of the Miocene-Pliocene constructional surface and partly because the deepest dissection in the last stage approximately coincides with the regions of low relief in the preceding mature topography.

The rocks of the Owyhee Upland consist mainly of lavas older than those exposed on the High Lava Plains, and the warped surface of the Owyhee Uplands disappears northward beneath the sediments and young basalt flows that fill the Snake River Downwarp. While the plateau parts of the Owyhee Upland are in a youthful stage of erosion, the Owyhee Mountains that rise above the general level are mature. The uplift of the Owyhee Upland probably coincided with that of the Central Mountains region but, being separated therefrom by the High Lava Plains, is so isolated as to constitute a separate subprovince.

COLUMBIA BASIN

General Statement

In this paper the name, Columbia Basin, is applied to the subprovince that lies north of the Blue Mountains and approximately coincides with the "Walla Walla Plateau section" of Fenneman,[8] who divided it into four districts: Eastern Margin, Coulee, Yakima and North Central Oregon.

Figure 3[8a] shows the revised divisions of the Columbia Basin which are considered of such size and of such decided differences in topography that they should be recognized as sections rather than districts, thus requiring the Columbia Basin to be given a subprovince rank. The authors advocate also that the name Columbia Basin replace "Walla Walla Plateau," as the area is not a plateau but consists essentially of basins drained by the Columbia River and its tributaries. The whole region and the individual lower central areas are surrounded by features of much higher relief. Furthermore when the people of the state use the name, "Columbia Basin," they refer to eastern Washington south and west of the Rockies and not to the entire drainage basin of the Columbia River. The word Walla Walla is used for a minor river valley tributary to the Snake and is never applied by the residents to eastern Washington as a whole.

The Columbia Basin has essential unity in that: (1) the area has the

[8] Fenneman: *op. cit.*, pp. 251–271.

[8a] This figure is drawn on the map of the "Landforms of the Northwestern States" published by Erwin Raisz and is used by his permission.

structure of a basin, (2) the characteristic bedrock is basalt, probably of Miocene age, and (3) it is surrounded by a rim of mountains. On the north and east the boundary of the Columbia Basin is determined by the overlap of the basaltic flows upon the crystalline rocks of the Rocky Mountains. On the northwest the course of the Columbia River for a considerable distance marks the contact between the lavas and old rocks.[9] On the south the boundary chosen is fixed by the dissected uplands of the Blue Mountains and associated uplifts. On the west the Cascade Range in Oregon rises sharply from a lava plateau and thus defines the boundary, but in Washington the border is obscure and in general is drawn to include the surfaces with dominant exposures of basalt within the Columbia Basin and areas of dominant dissection within the Cascades.

Decided differences in topography permit the Columbia Basin subprovince to be classified into six sections, and the names chosen indicate the type of relief characteristic of the unit. In Washington, the *Central Plains* section lies in the middle of the Columbia Basin and is surrounded by higher country which is divided into the *Yakima Folds* on the southwest and west, the *Waterville Plateau* on the northwest, the *Channeled Scablands* on the northeast, and the *Palouse Hills* on the east. Most of the subprovince situated between the Blue Mountains and the Columbia River is called *North Central Oregon Plateau.*

Section Descriptions

Central Plains

The Central Plains section lies near the center of the Columbia Basin and is surrounded by higher land of varied relief. The Central Plains occupy the major depressed portions of the Columbia Basin and, in Washington, ridges extending into the area from the west nearly separate two structural downwarps, the Quincy Basin on the north and the Pasco Basin on the south. The Central Plains have a basement of thick basalt flows, above which is a covering of fluvial, lacustrine and aeolian sediments, at many places of considerable thickness, that range in age from late Miocene to Recent. Most of the region is in a youthful stage of erosion, although some surfaces have reached maturity. The area is drained by the Columbia and some major tributaries, and in the resulting valleys and shallow basins, wide terraces and alluvial slopes have developed; the whole region presents a different appearance from the higher lands that enclose it. Boundaries on the west and northwest are quite definite. This is also the case on the south where the Horse Heaven uplift, a part of the Yakima

[9] Bailey Willis: *Changes in River Courses in Washington Territory Due to Glaciation,* U. S. Geol. Surv., Bull. 40, 1887, p. 7.

Folds, extends from the Cascades almost to the Blue Mountains. However, a gap at the east end of the Horse Heaven Hills connects with the Umatilla Basin, a flattish area in Oregon a score of miles wide, which is included with the Central Plains. On the northeast and east the plains grade gradually into the Channeled Scablands and the Palouse Hills, and the determination of the boundary is more difficult than elsewhere.

Yakima Folds

The term Yakima Folds is applied to a series of anticlinal ridges and faulted uplifts with associated valleys, generally synclinal, that extend eastward from the southern half of the Cascade Mountains in Washington between the Columbia River on the south and the Badger Mountains on the north. The region is characterized by rather narrow ridges of sharply upfolded basalt flows that alternate with broad down-warped valleys. The topography of the entire section is dominated by its structure, the elevations being primarily upfolds and the main valleys downfolds; some of the uplifts, notably the Horse Heaven Hills result from faulting.[10] Two of the ridges, the Saddle Mountains and Frenchman Hills, extend across the Columbia River into the Central Plains, nearly separating the Pasco and Quincy basins. The Horse Heaven uplift extends the farthest of all to the eastward, and the Columbia River cuts across the far end of this in a mighty water gap nearly 2,000 feet deep called the Wallula Gateway. Two periods of post-lava uplift may have occurred in the Yakima and adjacent Cascades region: The last uplift probably came in late Pleistocene and resulted in much erosion from the Cascade Mountains and deposition of sediments to the eastward which Warren [11] believes caused the course of the Columbia River to be changed many miles to the present valley via Wallula. Incised meanders and watergaps in the ridges between Ellensburg and Yakima are noteworthy. Smith and Willis [12] believed that a peneplain exists in the Cascade Range and extends into the Columbia Basin,[13] but other interpretations have been made of the supposed peneplain, for example by Waters.[14] On the northeast the Badger Mountains rise above the level

[10] Edwin T. Hodge: *Columbia River Fault Scarp,* Geol. Soc. Am. Bull., vol. 42, pp. 923–984, Dec. 31, 1931.

[11] Chas. R. Warren: *Course of Columbia River in South Central Washington,* Am. Jour. Sci., vol. 239, pp. 209–232, March 1941.

[12] George Otis Smith and Bailey Willis: *Contributions to the Geology of Washington,* U. S. Geol. Surv., Prof. Paper 19, 1903.

[13] Smith and Willis, *op. cit.,* pp. 9–39. Also George Otis Smith, Ellensburg Folio, U. S. Geol. Survey, 1903.

[14] Aron C. Waters: *Resurrected Erosion Surface in Central Washington,* Geol. Soc. Am. Bull., vol. 50, pp. 638–659, April 1, 1937.

of the Waterville Plateau and form the last of the folds in that direction. The Yakima Folds section as a whole has very youthful topography; the surfaces correspond to the original structures and the uplifts are as yet little reduced by erosion. The valleys between the ridges are mostly filled with continental sediments, the last of which are of Pleistocene age. In the Yakima Valley these have been reworked by the Yakima River and its tributaries to form a series of terraces and alluvial slopes which cause this detritus-filled area to resemble the Central Plains in relief, bedrock and soil. However, as it is surrounded by ridges, the Yakima Valley is distinctly separated from the plains and thus cannot be included in that section.

Waterville Plateau

The northwest corner of the Columbia Basin has been little disturbed by earth movements since the Miocene, and the lava flows are approximately horizontal. Being higher than the flat Quincy Basin to the south, the area is called the Waterville Plateau. The section has been cut into three units by two canyons, the northern portion, called the Okanogan Plateau, being separated from the rest by the Columbia River canyon,[15] and an eastern part is cut off by the gorge of the Grand Coulee. The Columbia River is usually near the edge of the basalt flows that covered older rocks on the lower slopes of the adjacent mountains.[16] The upper canyon walls are of black basalt in contrast to the lower parts, which often are excavated in ancient granite and other crystalline rocks. The Waterville Plateau has a youthful topography and, except for the major canyons, the surface has been little modified by erosion. The canyons of the Columbia River and the Grand Coulee, which were completely cut across the plateau, and Moses Coulee, which was eroded almost across the area, were mainly excavated during the Pleistocene by rivers of glacial melt water.[17] Papers by Bretz, Flint and Waters mentioned elsewhere describe glacial and older geologic features of the section. Fenneman included the Waterville Plateau with his Coulee district, along with most of the Central Plains and Channeled Scablands, but the topography of these regions differs so markedly from each other that their recognition as sections now seems justified.

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[15] Joseph T. Pardee: *Geology and Mineral Deposits of the Colville Indian Reservation, Wash.*, U. S. Geol. Surv., Bull. 677, pp. 46, 1918.

[16] Walter M. Chappell: *The Effect of Miocene Lavas on the Course of the Columbia River in Central Wash.*, Jour. Geol., vol. 44, pp. 379–386, 1936.

[17] J. Harlen Bretz: *The Grand Coulee*, New York, 1932.

Channeled Scablands

The term Channeled Scablands was proposed by Bretz[18] to describe a region with unique topography that has been superimposed on the western part of the Palouse Hills and certain other areas adjoining the Central Plains of eastern Washington. Besides papers by Bretz, other contributions have been published by several geologists on the Scablands and glaciations in Eastern Washington, including Allison, Flint and Hobbs.[19] The Channeled Scablands section is a zone of "island-like" hills covered with loessial soil that rise above the interlacing channels of bare lava rock. The term, Channeled Scablands, is directly applicable only to those parts from which the superficial deposits have been removed, so that strictly speaking, the area would be described as Palouse Hills mixed with scablands. The remnants of the original Palouse Hills have a mature topography but the Channeled Scablands that have been incised into this surface have the characteristics of youth.

The Scablands have been adequately described by Bretz in several papers published between 1923–1932, and their description will be omitted here, except to say that in general they are characterized by deep, rock-bound lakes, potholes, steep cliffs, ponds and swampy meadows, rocky buttes, water-eroded pinnacles and turrets of black basalt, flat-topped mesas, dry falls, abandoned cascades, and dusty or rock-bound deserted water courses. The boundaries of the section were determined by the prevalence of scabrock compared to the amount of surfaces unaffected by erosion by glacial melt water. Where the scabland channels are very minor, the areas are included with the Palouse Hills on the east, or with the Waterville Plateau on the west. In the latter case, both the Grand Coulee and Moses Coulee are really scabland channels.

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[18] J. Harlan Bretz: *The Channeled Scablands of the Columbia Plateau,* Jour. Geol., vol. 31, pp. 617–649, 1923.

————————: *The Channeled Scablands of Eastern Washington,* Geog. Review, vol. 18, pp. 446–477, 1928.

[19] Ira S. Allison: *Flint's Fill Hypothesis of Origin of Scabland,* Jour. Geol., vol. 49, pp. 54–73, Jan.–Feb., 1941.

Richard F. Flint: *Stratified Drift and Deglaciation of Eastern Wash.,* Geol. Soc. Am., Bull., vol. 47, pp. 1849–1884, Dec. 31, 1936.

————————: *Pleistocene Drift Border in Eastern Washington,* Geol. Soc. Am., Bull., vol. 48, pp. 203–232, Feb. 1, 1937.

————————: *Origin of the Cheney-Palouse Scabland Tract, Washington,* Geol. Soc. Am. Bull., vol. 49, pp. 461–523, March 1, 1938.

William H. Hobbs: *Discovery in Eastern Washington of a New Lobe of the Pleistocene Continental Glacier,* Science, vol. 98, No. 2541, pp. 227–230, Sept. 10, 1943.

Palouse Hills

In eastern Washington, from the vicinity of Spokane south to near Walla Walla, and extending into Idaho in the vicinities of Coeur d'Alene and Moscow, is a fertile, rolling, hill country, called the Palouse Hills, which forms the eastern part of the Columbia Basin. The Palouse Hills are mature; relief is generally less than 400 feet. Most of the surface soil is probably of loessial origin and usually covers the basaltic bedrock to a considerable depth. Small areas of old metamorphic and igneous rocks occur where hills of the pre-lava surface were not covered by the lava flows. North of the Snake River the Palouse Hills are characterized by gentle south and southwest slopes and steep north and northeast slopes, which in places form concave amphitheaters. Apparently this peculiar shape of the hills is a recent topographic expression and, according to Rockie,[20] resulted from a combination of rainwash, wind-work, and nivation.

The Palouse Hills begin on the north approximately at the Spokane River. On the west the section grades into the Channeled Scablands and the Central Plains. The east boundary is the Rocky Mountains and follows a sinuous course with irregular embayments of Palouse topography extending into Idaho from Washington. On the south the section extends beyond the Snake River nearly to Walla Walla. The Palouse changes in altitude from about 2,500 feet along the Idaho line to 1,000–1,500 feet southwestward, where the hill slopes become longer and less steep and the section merges into the Central Plains. The "Palouse Country" was included by Fenneman in his "Eastern Margin district."

North Central Oregon Plateau

This section includes the region of sloping, moderately dissected basalts that extends from the Cascade Range eastward between the Blue Mountains and the Columbia River in north central Oregon. From the Columbia River to the mountains the inclined plateau increases in altitude by nearly 3,000 feet. Here the Deschutes, John Day and other streams have cut deep, narrow canyons between which are broad, sloping and rolling surfaces. The North Central Oregon Plateau as a whole is in a youthful stage of erosion. Only a few minor uplifts disturb the usual sloping surface of the section. Although some Tertiary sediments outcrop, especially in the John Day valley, the usual bedrock is basalt. In 1940 Freeman[21] called the section the Deschutes-Columbia Plateau, but in the present paper it seemed

[20] William A. Rockie: *Snowdrifts and the Palouse Topography,* Geog. Rev., vol. 24, pp. 380–385, 1934.

[21] Freeman, *op. cit.,* 1940, p. 19.

best to revert to the older term introduced by Fenneman, of North Central Oregon, with the addition of the word "plateau." This was done in order to avoid too frequent use of the word "Columbia" when applied to physiographic subdivisions. In comparison with the North Central Oregon district of Fenneman and the Deschutes-Columbia Plateau of Freeman, the present section is smaller and has closer unity of surface features as the result of the elimination of: (1) the rough and mountainous country of the upper John Day and Deschutes rivers and (2) the cinder cones and recent lava flows near Bend, neither of which areas had characteristics resembling other parts of the Columbia Basin.

CENTRAL MOUNTAINS

General Statement

This division includes a complex group of mountain ranges and dissected uplands that extend from the eastern margin of the basalt flows in western Idaho wesward across Oregon to the Cascade Mountains. The major portion, lying mostly in Oregon, is known locally by the broad term of Blue Mountains. Within the Blue Mountains are a number of minor ranges, small plateaus, and basins. East of the Blue Mountains are dissected highlands above which rise the separate uplifts of the Wallowa and Seven Devils mountains (Fig. 3).

There are several large exposures of granitic, metamorphic, and deformed sedimentary rocks of pre-Tertiary age in the Central Mountains, but most of the surface is upon deformed and eroded lavas and associated sedimentary deposits. Lindgren[22] believed that the pre-Tertiary rock exposures were derived largely from islands of an ancient matureland that remained above the lava floods. Some small tracts are undoubtedly of this origin, but lava outliers near the uppermost levels of most old-rock areas indicate that post-lava erosion has greatly widened the exposures. The character of much of the Central Mountains surface was determined by deformation and erosion[23, 24, 25] within the extended period of lava extrusions, especially in the time immediately following the extrusion of the Miocene basalts.

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[22] Waldemar Lindgren: *Gold Belt of the Blue Mountains*, U. S. Geol. Survey, 22nd Ann. Report, Pt. 2, 1901, pp. 596–598.

[23] R. L. Lupher: *Construction of the Silvies Surface of Central Oregon*, (abst.) Geol. Soc. Amer., Proc. for 1936, p. 319.

[24] W. D. Wilkinson: *Geology and Map of the Round Mountain Quadrangle, Oregon*, Ore. Dept. Geol. Min. Ind., 1939.

[25] E. T. Hodge: *Geology of North Central Oregon*, Ore. State Mono., Studies in Geol., No. 3, 1942.

In the southern and western Blue Mountains a mature surface with relief of 2,000 feet was developed before the end of the Pliocene epoch, though some of the low portions of the surface were buried beneath continental beds and lava flows so that monadnocks of Miocene and older rocks rose above flat constructional plains. In the northeastern part of the subprovince a similar surface with a maximum relief of about 400 feet was formed. The early erosional episode has not been recognized in the eastern and central parts of the subprovince, but presumably the large tracts of mature mountains on and near the pre-Tertiary basement rocks were developed at this time.

The final episode of deformation apparently was delayed until the early Pleistocene. It was largely one of regional uplift and local warping and faulting that marked out most of the present basins, plateaus, and ranges of the Central Mountains and elevated the highest portions to altitudes of 9,000–10,000 feet above sea. The deformation modified the flat constructional surface of the Pliocene, elevated the monadnocks, and extended into areas of hitherto little-deformed Columbia River lava. The present surface is generally mature on the monadnock areas and in all the highest portions of the mountains, and is dominantly youthful where the canyons of Pleistocene age cut deeply into the rolling mature surface of low relief or into uplifted young lava plains.

Though all three sections probably retain the effects of Tertiary deformation and erosion and all record deformation and deep dissection during the Pleistocene, there are important differences between them. Block-faulting characterizes the Wallowa-Seven Devils section; warping is predominant in the Blue Mountains; and regional uplift and deep dissection with little warping or faulting characterizes the Tristate Uplands.

The eastern boundary of the province is drawn at the contact of the lavas with the mature topography of the Northern Rocky Mountains. The boundary with the High Lava Plains is sharply defined on the southwest, where the flat lava plains give way to tilted and dissected mountain slopes or end abruptly against steep, mature surfaces of the Miocene-Pliocene erosional episode; but, in the southeast, low portions of the mountains lie adjacent to the most dissected part of the Plains, and the boundary is more arbitrary. On the west, the Central Mountains abut against the Cascade Range, and the boundary is clearly indicated by the contrast of the deeply eroded uplift of the Mutton Mountains with the young constructional lava ridge of the Cascades. The boundary with the Columbia Basin is not clearly defined because the Columbia River basalts are inclined gently northward and, though the dissection decreases with altitude, the major streams cut deeply into the lava far out into the basin. Therefore,

the boundary of the mountain province is arbitrarily drawn so as to include, insofar as possible, areas where canyons of the present cycle constitute more than one half of the present land surface. As a rule, this places the northern boundary of the province at or near the 3,000 foot contour and excludes areas in which the lavas are generally concealed by later sediments.

Section Descriptions

Blue Mountains

This section includes a complex group of mountain ranges and dissected highlands that spread widely over central and northeastern Oregon and extend into southeastern Washington. Fenneman[26] excluded the western portion of the mountains from his "Blue Mountain section" presumably because the region was little described at the time. However, it is continuous with the mountains to the east, and the highest portions rise to altitudes of well over 6,000 feet above sea and over 2,000 feet above the High Lava Plains.

The western portion of the Blue Mountains section, which includes the Ochoco, Maury, and Mutton mountains, is largely a residual mass of old mountains produced by Miocene deformation and ensuing erosion. Early Tertiary and pre-Tertiary rocks are widely exposed, and the mature surface passes abruptly beneath the young lava plains on the south and southeast, abuts against the young constructional ridge of the Cascades on the west, and grades northward into the less dissected surface of the Columbia Basin. The Aldrich, Strawberry, and Ironside mountains are parts of a maturely eroded structural ridge that continues eastward from the Ochocos; it rises to 9,600 feet above sea level at Strawberry Butte. South of the mountains, the Silvies plateau descends gradually to the High Lava Plains. Once its surface was continuous with the plains but was deformed and considerably dissected by streams that converge into several structural basins. Several monadnocks remaining from the Miocene-Pliocene erosion rise above the plain remnants. North of the mountains the structural and erosional depression of the John Day Basin records early deformation, dissection, subsequent filling of the basin, and later warping and dissection. The John Day Uplands, a complex group of dissected plateaus, anticlinical ridges, and basins, extend northward from the John Day Basin and culminate in the Umatilla Mountains and Umatilla Plateau.

The deeply eroded, mature surface of the region called the Elkhorn-Greenhorn mountains rises to altitudes of 7,000–9,000 feet in the central part of the Blue Mountain section. Pre-Tertiary rocks are extensively ex-

[26] Fenneman, *op. cit.*, p. 225–273.

posed. Lindgren (1901) stated[27] that "the Blue Mountains stood like an island in a basaltic sea." Though he apparently referred only to the Elkhorn-Greenhorn district, some later writers have translated the statement literally to apply to the Blue Mountains in a broad sense. Even in this high central district, lava outliers show that post-lava erosion accounts for a large part of the old-rock exposures. The Elkhorn-Greenhorn surface grades eastward into dissected structural basins and ridges. Altitudes range from 2,000 to 6,500 feet; pre-Tertiary rocks are widely exposed beneath Tertiary lavas and continental beds. The Grande Ronde Arch, an anticlinical ridge of Columbia River basalts, extends northward for 100 miles from the Elkhorn-Greenhorn mountains. The last episode of dissection has produced a mature surface along the medial high portion, which reaches above an altitude of 6,000 feet, but the flanks of the arch are of youthful aspect.

Wallowa-Seven Devils Section

This section includes two mountainous uplifts separated by a lower tract of the former lava plain and by the canyon of the Snake River, which reaches depths of more than 6,000 feet. It is characterized by block-faulting and, in the highest portions, by deeply cut mature surfaces, beneath which are large exposures of granodiorites, greenstones, and marine sedimentary rocks. Columbia River basalts predominate only on the periphery. Glaciated canyons several thousand feet deep radiate from the high central areas. Outliers[28] of Columbia River basalt on some of the high peaks of the Wallowa Mountains show that the present surface did not inherit its rugged character from an island of pre-lava topography. Here, as in other parts of the Central Mountains, the mature surface and wide exposures of pre-Tertiary rocks are caused primarily by deformation and erosion prior to the Pleistocene.[29] Faults[30] were important in the growth of the Wallowa uplift and, in the area of lavas that surround the old rocks, they have a marked effect upon the present drainage pattern.[31]

The Idaho portion of the section was described recently by Anderson[32]—

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[27] *Op. cit.*, p. 597.

[28] W. D. Smith and W. R. Lowell: *Geology and Physiography of the Northern Wallowa Mountains, Oregon*, Ore. Dept. Geol. and Min. Ind., Bull. 12, 1941, p. 19.

[29] C. P. Ross: *The Geology of a Part of the Wallowa Mountains*, Ore. Dept. Geol. and Min. Ind., Bull. No. 3, 1938, p. 73.

[30] Smith and Lowell: *op. cit.*, p. 30.

[31] D. C. Livingston: *Certain Topographic Features of Northeastern Oregon and Their Relation to Faulting*, Jour. Geol., vol. 26, 1928, pp. 694–708.

[32] *Op. cit.*, pp. 206–222.

who termed it the "Seven Devils section" but recognized its close affinity with the Wallowa region of Oregon. The high northern end of Anderson's section, the Seven Devils Mountains, possesses a deeply cut mature surface on basement rocks and surrounding lavas and it closely resembles the Wallowa surface. The large southern portion is lower, less dissected, and largely underlain by lavas, but its affinity with the rest of the section is indicated by predominance of block-faulting.

Tristate Uplands

This section is distinctly lower than the Seven Devils, Wallowa, and Blue mountains, and it is not clearly set off from the eastern margin of the Columbia Basin. Its affinity with the Central Mountains is indicated by the generally high altitude, warping of the lavas, deep canyons, and the absence of the sedimentary cover of the lavas that is so characteristic of the eastern Columbia Basin. The dominant character of the section is that of a gently warped upland surface of Columbia River basalt which has been deeply incised by the Clearwater, Salmon, Snake and Grande Ronde rivers and their tributaries. Most of the upland lies between altitudes of 3,000 to 5,000 feet. The Snake River has carved its canyon more than 4,000 feet deep near the Seven Devils Mountains and the incised meanders of the Grande Ronde reach a maximum depth of 3,000 feet. The canyons are the result of Pleistocene diastrophism; between them are large remnants of a mature erosion surface of low rolling hills, in which the relief is generally less than 200 feet. An excellent description of the Idaho part of the section was presented by Anderson[33] under the heading of "Craig Mountain Section" and will not be repeated here. In general the uplands slope north and west toward the Columbia Basin, and much of the area was once included by Freeman[34] with the Columbia Basin; but all three authors are now agreed that the area should be included with the Central Mountains.

THE HIGH LAVA PLAINS

General Statement

That portion of the Columbia Intermontane province here treated as the High Lava Plains subprovince (Fig. 3), is south of the Northern Rocky Mountains and the Blue Mountains, and is north of the Basin and Range province and the Owyhee Upland. It has been perhaps the subject of more written discussion, from the physiographic standpoint, than most other comparable areas of the Pacific Northwest. According to Fenne-

[33] *Op. cit.*, pp. 217–219.
[34] *Op. cit.*, 1940.

man,[35] it includes, in part at least, the Snake River Plain, Payette and Harney sections. Freeman[36] proposed that the region be subdivided into the Snake River Plain, Payette (revised), Owyhee Plateaus and Transition (Harney) sections; and Anderson,[37] who dealt only with the portion included in Idaho, would zone that general area into the Snake River Plain (revised), Owyhee, and Seven Devils sections.

Fenneman's classification, because of its priority and rather wide acceptance, has been taken as the basic study and the treatment is somewhat colored by Fenneman's choice of nomenclature. In the present paper it is suggested that the High Lava Plains be divided into three units; one of these, the Snake River Plain is essentially unchanged, the other two are new, namely the Malheur-Boise, and the Harney-High Desert sections.

The High Lava Plains subprovince extends in a general east-west arcuate zone across much of southern Idaho and southeast Oregon. It is convex to the south and is bounded on the east and west by the Teton Mountains and Cascade Mountains respectively. The division, throughout its entire expanse, is comprised dominantly of young, flat-lying basalts, recent cinder cones, or intervolcanic sediments. It is sufficiently distinctive to warrant recognition as a subprovince because: (1) the plains-like, extrusive surfaces of the High Lava Plains region are younger and have more immature drainage, with much less dissection, than most other extrusive rock areas of the Columbia Intermontane province; (2) intercalated sediments, common in the High Lava Plains, are not found so extensively in other sectors; (3) recent cinder cones are numerous and the High Lava Plains are the only part of the Columbia Intermontane province where this is true; (4) the basalts and sediments of the new division have not undergone the appreciable deformation that has taken place in some other sectors of the Columbia Intermontane province.

Section Descriptions

Snake River Plain

It is proposed that the name Snake River Plain continue to be used for the eastern-most section of the lava plains of southern Idaho. With only minor modifications, it is essentially the area as originally defined by Fenneman[38] and described by him as the Snake River Plain section.

The outstanding and distinguishing features of this area have been so

[35] N. M. Fenneman: *op. cit.*, pp. 225–246, Pl. 1.
[36] O. W. Freeman: *op. cit.*, pp. 73 and 74, Fig. 14.
[37] A. L. Anderson: *op. cit.*, pp. 206–222.
[38] N. M. Fenneman: *op. cit.*, pp. 238–244.

thoroughly presented by Fenneman, Anderson,[39] and others, that only a brief résumé of the most noteworthy characteristics is necessary here. The dominant feature is that of a vast, essentially flat, plains-like surface marked here and there, as in the "Craters of the Moon" area, by mounds of scoriaceous basalt and recent cinder cones. Underlying the wide expanses of these high plains are nearly horizontal, black, basalt flows of Quaternary (Snake River) age that were poured out into the trough of the Snake River downwarp.[40] The depth of weathering generally is shallow, and in some places, particularly where recent vulcanism has occurred, it is generally negligible.

Except for the Snake River, which courses westerly near and along the southern border of the section, the region is but little dissected and perennial streams are scarce. Most of the water introduced to the area is, it seems, disposed of by infiltration; and subsurface drainage through the basaltic rocks is a pronounced feature. The erosion stage over large areas is still in an initial phase. The youthful character of the Snake River itself is evidenced by the waterfalls, rapids and steep canyon walls of its channel. The Snake River Plain encompasses approximately 14,000 square miles and slopes gradually westward from 6,000 feet, more or less, to about 3,500 feet above sea level.

The northern and eastern limits of the section are quite precise and, therefore, have been generally accepted. They are represented by the line of older mountain barriers which the basaltic extrusives found as dams to further spreading, and are, respectively, the Northern Rocky Mountains and Middle Rocky Mountains. The southern boundary generally has been established by connecting the northern extremities of linear ranges which characterize the adjoining Basin and Range province. The western border of the Snake River Plain section, however, is rather a generalized one. Fenneman[41] saw fit to place this limit just west of 115° west longitude, whereas Anderson[42] has recommended that the boundary line in this locality be dispensed with entirely.

Although the authors grant that a physiographic break is not abrupt in this zone, the fact remains that a transitional change does take place westward from the upper part of the Snake River Plain region. That is, the typical surface configuration of the country, as delineated chiefly by rock characteristics and degree of dissection, becomes different in the vicinity of the 115th parallel of longitude. For example, near King Hill and

[39] A. L. Anderson: *op. cit.*, pp. 210–212.
[40] A. L. Anderson: *op. cit.*, pp. 210–211.
[41] N. M. Fenneman: *op. cit.*, p. 238.
[42] A. L. Anderson: *op. cit.*, p. 212.

Bliss, Idaho, the Snake River downwarp is: (1) lower than it is further east; (2) to the west lake beds and other sedimentary rocks intercalated with basalt flows become a dominant characteristic; and (3) the stage of erosion is, in general, that of late youth-early maturity rather than early youth. These features become even more pronounced westward through Idaho into Oregon. For this reason it is here proposed that the line of demarcation be maintained much as originally suggested by Fenneman and also, that an adjoining section be created and known as the Malheur-Boise section.

Malheur-Boise

This proposed section includes essentially the middle, east-west portion of Fenneman's Payette section, and also the western part of Anderson's Snake River Plain. The contiguous areas of western Idaho and eastern Oregon at the latitude of the high Lava Plains belt are, as above noted and as will be discussed, physiographically similar. Therefore, they are combined and are here treated as a single, rather homogeneous unit which, as thus established, becomes the center section of the new High Lava Plains subprovince.

The land surface of this section is, with some exceptions, sharply incised. Relief usually is abrupt because of deep and ramified stream dissection of the undeformed (Pliocene?) lake sediments and cinder beds ,which are the dominant or prevailing rock types exposed on the surface. The predominance of essentially flat-lying sediments intercalated with variable amounts of basalt becomes particularly marked in the central portion of the section. There are some plains-like expanses in the vicinity of Weiser, Payette, and Caldwell, Idaho, and near Vale, Oregon, but these are of minor and localized extent. In addition, there are some tracts of young Quaternary basaltic extrusives which serve as cap rocks to the sediments exposed below, but these areas also are usually limited.

The elevation of the Malheur-Boise section varies from maxima of about 3,500 feet above sea level at the eastern and western extremities to 2,500 feet, more or less, near the Idaho-Oregon line. That is, the prevailing regional slopes and drainages are towards the central portion of the region. The section covers approximately 10,000 square miles and is about equally divided between Idaho and Oregon.

The distorted, extrusive and intrusive rocks of the Owyhee Upland subprovince constitute a definite border to most of the southern limits of the Malheur-Boise section, although it should be noted that the western extent of this boundary becomes somewhat less pronounced because of the proximity of Basin and Range topography. In fact, the exact limits in

this particular area have been, and are still to some degree, quite generalized. On the north, the section is delimited, from east to west, respectively, by the marginal upland topography of the Northern Rocky Mountains, the Wallowa-Seven Devils section, and the Blue Mountains.

The eastern and western boundaries of the Malheur-Boise unit are the Snake River Plain, as previously noted, and the Harney-High Desert sections, respectively. The western limit is placed just east of 119° west longitude because approximately along this line the flat-lying, broad expanses of relatively fresh lava, covered in places by a veneer of sediments and ash (Pliocene to Recent), which characterize the Harney-High Desert section, become the dominant physiographic feature.

In the writers' opinion, the new Malheur-Boise section as thus delimited, possesses a greater physiographic unity than Fenneman's original Payette section which, he noted,[43] is lower than adjacent sections but in which he included mountains over 8,000 feet in elevation. Further, this proposed unit is not confined by state boundaries.

Harney-High Desert

The Harney-High Desert section is remarkably similar to the Snake River Plain section. It may aptly be considered as the western counterpart of the Snake River Plain in the High Lava Plains subprovince. For example, Pliocene and later lavas, ash accumulations, and cinder buttes blanket the area in much the same manner as in the easternmost section, and their physiographic expressions are analogous. In fact, the volcanic phenomena, such as cinder cones and patches of very recent lavas that are present in the "Craters of the Moon" region, are duplicated faithfully in the area near Bend, Oregon. The surface rocks of the Harney-High Desert section are scarcely affected by weathering or erosion, and the scanty desert vegetation and comparatively thin veneer of drifting sand or ash are characteristic of this dry region. Except for the extreme northwestern portion of the section, which is incised and drained by the Deschutes River, the region has but poorly integrated, youthful stream tracts and ephemeral lakes. Localized interior drainage is a common feature and is directed either into the Harney Basin south of Burns, Oregon, or into the Great Basin.

There is some evidence of relatively small fault displacements at various localities of the section, but the physiographic effects of these features, which are probably related to the Basin and Range structures to the south, are minor and so subdued as to have little consequence in the picture as a

[43] N. M. Fenneman: *op. cit.*, p. 244.

whole. Fenneman[44] and Piper[45] have thoroughly described the Harney-High Desert section. It may further be noted, however, that about 13,500 square miles are encompassed by the limits of the unit as here drawn, and the approximate mean elevation is 4,500 feet above sea level.

On the north, northwest, and west, the elevated, more dissected surfaces and warped rocks of the Central Mountains subprovince and the Cascade Mountains respectively are different from the typical Harney-High Desert section, and so can be used with certainty to establish a northerly and westerly limit.

The Basin and Range topography along the southern border of the section does not begin abruptly, and so some difficulty in drawing a specific boundary line presents itself. Although the physiographic contrast which develops is a transitory one, the line has been drawn along the approximate northern limits of the typical Basin and Range features. That is, the zone, where individual ranges, separated by intermont basins, cease to be the dominant characteristic, has been selected as the general line of demarcation. This leaves several small faults to be included in the Harney-High Desert section. The eastern limit of the section, as before mentioned, has been set tentatively just east of 119° west longitude.

OWYHEE UPLAND

Fenneman[46] included all of southwestern Idaho in his Payette section. Anderson[47] was the first to suggest applying the name "Owyhee section" to the southern part of the subdivision and, in his treatment, has described the area. The name Owyhee, as thus proposed by Anderson, has been adopted by the writers to apply to the elevated subprovince of the Columbia Intermontane province which lies in southwestern Idaho, southeastern Oregon and northern Nevada (Fig. 3). Unfortunately the full geomorphic details of the Owyhee region are not as well known as those of the rest of the Columbia province and, therefore, only the broad features will be described. The southern and western limits of the division can be drawn only approximately.

The Owyhee Upland is a high and, in some places, faulted plateau which differs from adjoining areas in that it (1) stands well above them in elevation, (2) is characterized by somewhat older plutonic and extrusive

[44] N. M. Fenneman: *op. cit.*, pp. 272–273.

[45] A. M. Piper, T. W. Robinson, anl C. F. Park, Jr.: *Geology and Ground-Water Resources of the Harney-Basin, Oregon*, U. S. Geol. Survey Water Supply Paper 841, 1939.

[46] N. M. Fenneman: *op. cit.*, 1931.

[47] A. L. Anderson: *op. cit.*, 1941.

igneous rocks, and (3) is more extensively dissected. The eastern part of the plateau is built mainly of rhyolites and quartz latites that are considered by Kirkham[48] to be late Tertiary in age and older than the Columbia and Snake River basalts. The western part of the Owyhee Upland is covered by basalt beds, except in localized areas where erosion has removed them to expose the older underlying rocks, and the basalts are frequently intercalated with continental sediments, including volcanic tuffs and ash of the Payette formation. On the north the plateau surface passes beneath the basaltic lavas and sediments that fill the downwarped Snake Plain and this surface forms the floor on which these materials were laid. Rising above the plateaus are the Owyhee Mountains and South Mountain. These two uplifts are about twenty miles apart and exist because sharp upwarping has occurred. The Owyhee Mountains attain elevations of 8,000 feet and more above sea level and rise 4,000 to 5,000 feet above the bordering High Lava Plains. Erosion has stripped the lava from much of the surface of these bulges, exposing their granite cores.

In the Owyhee Upland stream dissection is pronounced and well advanced. The Owyhee River has carved a remarkable canyon across the upwarped plateau in southeast Oregon, and tributary canyons still further dissect the surface to form what is locally called the "Rimrock Country." The greater elevation and degree of erosion of the Owyhee region presents a strong contrast to the contiguous Upper Snake Plain and the Malheur-Boise sections to the north. It also differs from the Basin and Range Province on the south, east, and west in that isolated ranges rising above extensive, flat intermont basins with numerous ephemeral lakes are not evident.

The Owyhee Upland as defined in this paper includes the Owyhee Mountains and several smaller domal uplifts whose drainage flows chiefly into the Pacific rather than into the Great Basin. However, drainage is not considered a complete criterion for delimiting purposes. Although the area encompassed is approximately 8,000 square miles, thus being small compared with the Columbia Basin, Central Mountains and High Lava Plains, nevertheless the Owyhee Upland region has such differences from the surrounding areas that the recognition of the unit as a subprovince of the Columbia Lava province appears justifiable to the writers.

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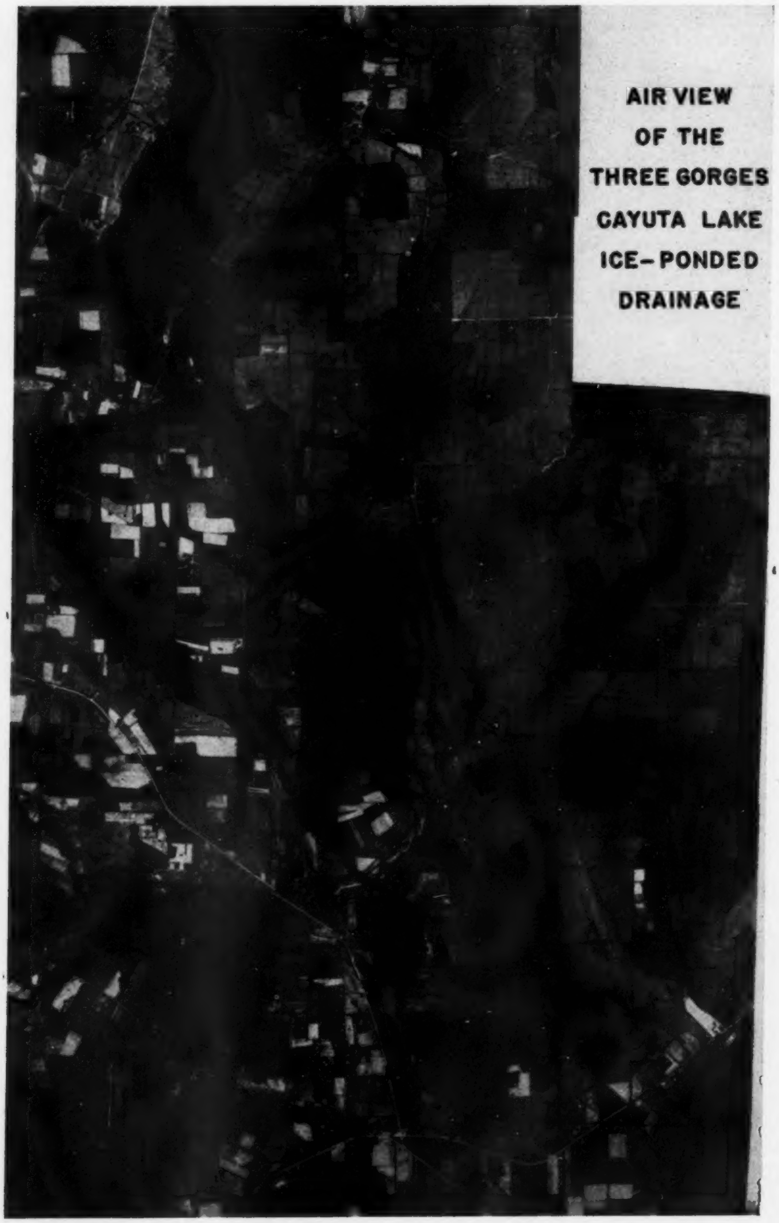
[48] V. R. D. Kirkham: *Igneous Geology of Southwestern Idaho*, Jour. Geol., vol. 39, 1931, pp. 579–587.



AIR VIEW
OF THE
THREE GORGES
CAYUTA LAKE
ICE-PONDED
DRAINAGE